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ELEMENTARY GENERAL SCIENCE

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J. M. HARRISON

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ELEMENTARY GENERAL SCIENCE

BOOK III

ELEMENTARY GENERAL SCIENCE
EDITED BY J. M. HARRISON
Book I With Illustrations and Diagrams
Book II With Illustrations and Diagrams
Book III With Illustrations and Diagrams

A PROGRESSIVE SCHOOL CHEMISTRY
BY J. M. HARRISON
Introductory Course, With Diagrams

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ELEMENTARY GENERAL SCIENCE

EDITED BY

J. M. HARRISON

SENIOR SCIENCE MASTER
BRISTOL GRAMMAR SCHOOL

BOOK III

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With Illustrations and Diagrams

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PREFACE

THIS book completes the course in Elementary Science from which it is suggested schools may select subject-matter for their own particular needs.

The treatment is on the same lines as that adopted in Books I and II, chapters 1–9 being arranged so as to interlink the sciences as far as possible. The remaining chapters deal with work which ought to find a place in a General Science course, or which it was necessary to include to meet the requirements of the more modern School Certificate General Science Examination Syllabuses, *e.g.* that of the Northern Universities Joint Board.

As in the case of the previous books, I have had the assistance of my colleagues, Mr. T. A. Morris, B.Sc., Mr. H. Dunnicliff, M.A., and Mr. W. E. Flood, M.A., in writing the text. Most of the work was done under very trying conditions, and I am very grateful to them for their efforts to produce the book in time to meet the demands of schools. Finally, I have to thank the various Publishers and Companies named, for their kindness in providing blocks and photographs for the half-tone illustrations.

J. M. HARRISON.

BRISTOL GRAMMAR SCHOOL.

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CHAPTER 1

CARBON MONOXIDE. METHANE. COAL-GAS

In Book II, Chaps. 16 and 17, we studied the commoner forms of the element carbon, the compound carbon dioxide and the carbonates. The element carbon enters into the composition of such a large number of compounds that it is customary to deal with most of them as a separate branch of chemistry, which is called *organic chemistry*. In this chapter we shall make a simple study of carbon monoxide and methane, then we shall consider some more complicated carbon compounds which are of biological importance.

A simple method of preparing carbon monoxide, CO

The apparatus needed to make this gas is shown in Fig. 1; it consists of a Kipp's apparatus, for producing carbon dioxide (Book II, p. 190), connected to an iron tube (gas-piping) containing iron filings. This tube is heated in a small furnace

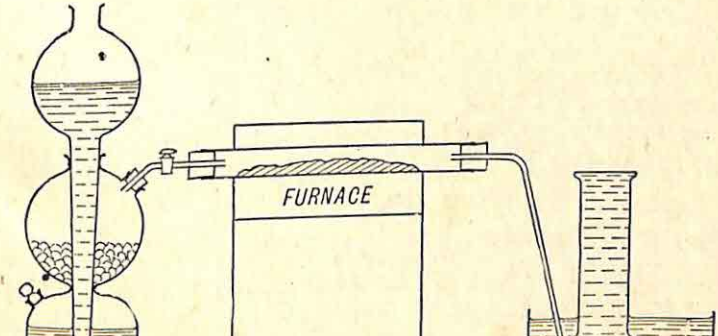


FIG. 1.

(3 burners) till it is red-hot. The delivery tube dips into a small trough containing a fairly strong solution of caustic soda. Why?

A *slow* stream of carbon dioxide is passed through the red-hot iron tube, and, after allowing air to escape, two small jars of gas are collected.

If the process is continued for some time, after allowing the iron tube to cool, the iron filings on examination are found to have a coating of the blue-black iron oxide. The reaction which takes place is :

$$3Fe + 4CO_2 \rightarrow Fe_3O_4 + 4CO.$$

The simple properties of carbon monoxide

The jars of gas collected in the above experiment are used to examine the properties of carbon monoxide. The gas is colourless and odourless ; it does not dissolve in water or caustic soda solution. Carbon monoxide has the same density as nitrogen, i.e. it is a little less dense than air.

Carbon monoxide readily burns with a characteristic blue flame. If lime-water is shaken up in a jar in which carbon monoxide has been burnt, the liquid becomes milky ; the product of combustion is carbon dioxide :

$$2CO + O_2 \rightarrow 2CO_2.$$

When a steady stream of carbon monoxide is passed over some heated copper oxide, the products are copper and carbon dioxide :

$$CuO + CO \rightarrow Cu + CO_2.$$

Carbon monoxide is thus a **reducing agent**, and, as such, it plays an important part in the smelting of iron ore in blast furnaces (Book II, p. 185).

The action of carbon monoxide on blood

To obtain a solution of blood, after washing the hands, one finger of the left hand is dipped in acetone, to sterilise it. Starting from the base of the finger, string is wrapped round it working towards the tip. With a sterilised needle the finger is pricked near the "quick," and two or three drops of blood collected in a boiling-tube half-full of water. The liquid thus obtained is diluted if necessary till it is yellowish. The solution is divided into two equal portions and coal-gas (p. 6) is slowly bubbled through one of them. The two solutions are now compared against a white background. That which has been subjected to the action of carbon monoxide is much pinker.

Carbon monoxide very readily combines with the hæmoglobin (Book I, p. 179) in blood, forming a stable compound **carboxy-hæmoglobin**; for this reason, it is a dangerous blood poison. Hæmoglobin which has been changed in this way cannot do its ordinary work. A person breathing air containing 1 per cent. of carbon monoxide becomes unconscious in a few minutes and dies soon afterwards.

In treating a case of suspected carbon monoxide poisoning, artificial respiration should first be employed. Oxygen should be given to the gassed person, who should be kept still and warm.

Dangerous sources of carbon monoxide

As carbon monoxide has no obvious odour, a person may inhale the gas without knowing it; there have been many fatal cases of carbon monoxide poisoning for this reason.

Coal-gas to-day contains a fairly high percentage of carbon monoxide, so that leaks should be repaired without delay. The accidental extinction of lights, especially where slot-meters are used, may be a source of danger.

Bathroom geysers, in which coal-gas is incompletely burnt, produce some carbon monoxide; such geysers should not be used without a vent pipe or free access of air to the room.

Anthracite stoves or coke fires give carbon monoxide, through incomplete combustion of carbon. Therefore the stoves must always be fixed so that the products of burning may pass up a chimney. Carbon monoxide flames are easily seen on top of a watchman's coke brazier, and such a fire should always be kept out in the open air.

When petrol vapour is exploded with air in the engine of a car, the chief products are carbon dioxide and water vapour. But the **exhaust gases** always contain some carbon monoxide, so that the engine of a car should never be run in a closed garage.

Water-gas and producer-gas

These two important fuels are mixtures of gases, each of which contains carbon monoxide. Water-gas has been mentioned previously (Book II, p. 12) ; it is made by passing steam through white-hot coke. and is a mixture of hydrogen and carbon monoxide :

$$C + H_2O \rightarrow H_2 + CO.$$

As this operation proceeds, the temperature falls, so that the steam has to be cut off, and air blown through the coke till it becomes white-hot. The air supply is then cut off and steam substituted. Steam and air are passed at intervals in this way, the water-gas being collected only when the steam is passing.

Producer-gas is simply a mixture of nitrogen and carbon monoxide made by passing air through red-hot coke in such a way that the oxygen is converted into carbon monoxide.

Mixtures of water-gas and producer-gas are used for running gas engines and as a substitute for petrol.

Hydrocarbons

Many compounds are known which are composed of the two elements carbon and hydrogen only ; all these compounds are called hydrocarbons. You should be careful not to confuse hydrocarbons with carbohydrates (p. 14).

The simplest hydrocarbon is **methane**, CH_4 ; it is also called **marsh-gas**, as it is formed by the decay of vegetation in marshy pools and streams. Miners call it **fire-damp**, for it is enclosed within the coal in certain mines and may cause serious explosions. Much of the gas escaping from petroleum wells (p. 12) is methane.

Other examples of well-known hydrocarbons are **acetylene**, C_2H_2, **benzene**, C_6H_6, obtained from coal-tar (p. 11), **turpentine** and **petroleum** ; the last two are mixtures of various hydrocarbons.

A simple method of preparing methane, CH_4

The apparatus required for making methane is shown in Fig. 2. The flask contains a few grams of aluminium carbide, and the tap-funnel is filled with dilute hydrochloric acid. The acid is dropped into the flask steadily, methane being given off with little or no heating. The gas is collected over water after air has been displaced from the apparatus. The reaction is :

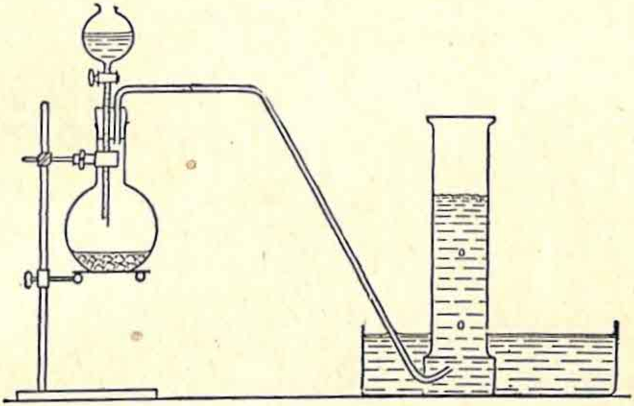


FIG. 2.

$$Al_4C_3 + 12HCl \rightarrow 4AlCl_3 + 3CH_4.$$

The simple properties of methane

Methane is a colourless gas, without any odour when pure ; as prepared above it will probably contain impurities, from the carbide, which give it a distinct odour. Methane is almost insoluble in water ; it is rather more than half as dense as air.

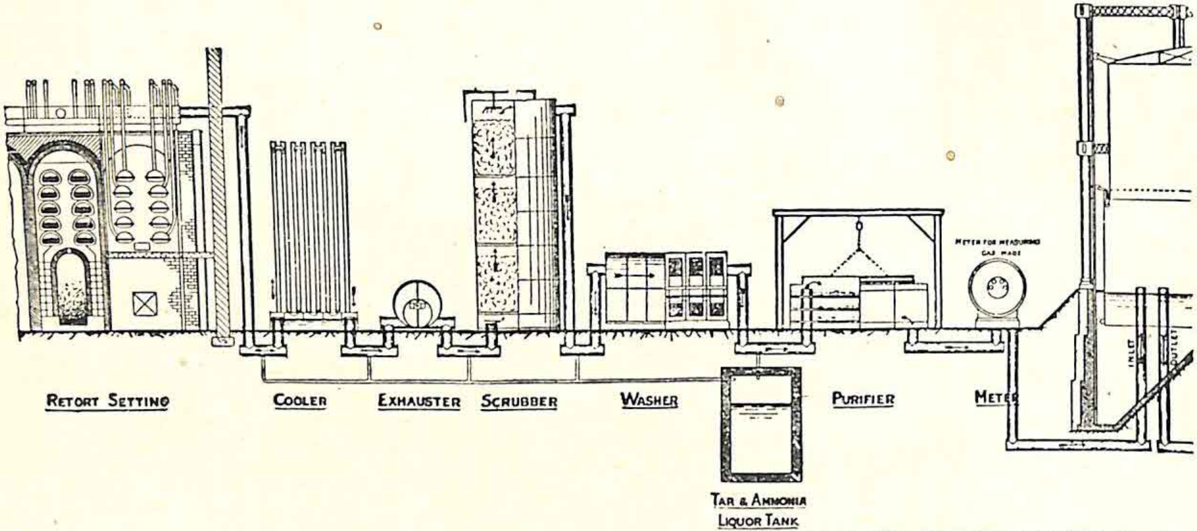
Methane burns, and, when the gas is pure, the flame is almost non-luminous. The products of combustion are carbon dioxide and water vapour :

$$CH_4+2O_2 \rightarrow CO_2 + 2H_2O.$$

A mixture of methane and air (or oxygen) in certain proportions is explosive ; special lamps (Book I, p. 234) are used by miners to avoid the ignition of such explosive mixtures.

EXPT.—*To prepare crude coal-gas.*

The apparatus shown in Fig. 3 is first set up. Note the position of the delivery tubes. Put several pieces of ordinary coal into the


RETORT SETTING
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PURIFIER
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FIG. 4.—PLANT FOR THE MANUFACTURE AND PURIFICATION OF COAL-GAS.

horizontal boiling-tube, and cool the vertical tube in a beaker of water. Heat the coal, at first gently, afterwards quite strongly. When air has been displaced from the tubes, ignite the crude gas. Continue heating till no more gas is evolved, then examine the contents of both boiling-tubes. (Do not pour the liquids into the sink.)

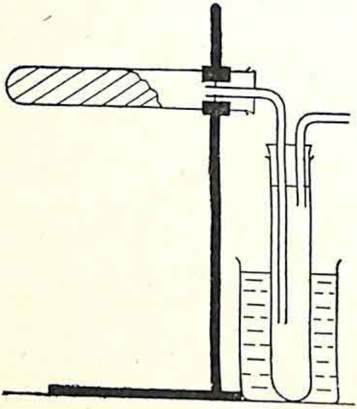


FIG. 3.

Coal-gas

The dry or destructive distillation of coal, as carried out in the above experiment, yields a greenish smoke, which on cooling gives two liquids and impure coal-gas. The two liquids are **gas-liquor**, a brownish watery liquid, and **coal-tar,** a thick, black stinking liquid. The crude coal-gas burns with a luminous, rather smoky flame. The residue remaining when all the volatile matter has been driven off from the coal is **coke.**

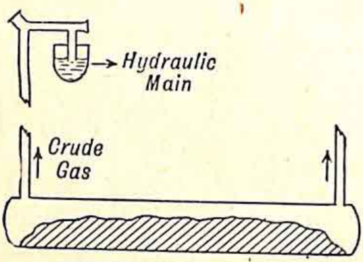
The coal-gas supplied by gas works is treated as indicated below, so that it can be burnt in large quantities without giving any objectionable products. The purified coal-gas is colourless and has a distinct odour. It does not dissolve in water, and it is less dense than air.

Coal-gas is essentially a mixture of hydrogen, methane and carbon monoxide ; its composition varies. All three gases burn with flames which give little light ; the luminosity of a coal-gas flame is caused by small quantities of other combustible gases and vapours, e.g. acetylene and benzene.

The manufacture of coal-gas

In this country alone something like 20 million tons of coal are used each year for making gas, so that you will readily understand that the industry is one of great importance. Besides its familiar household uses, coal-gas is employed in many industries as a fuel, in making coins, since a reducing atmosphere is essential, and in " running in " engines of various kinds, so that the cylinders are kept clean for inspection.

In addition to coal-gas, this industry produces important by-products, e.g. coal-tar, from which many valuable substances are isolated (p. 11).



HORIZONTAL RETORT.

FIG. 5.

The various stages in the manufacture of coal-gas, illustrated in Fig. 4, are as follows :

(1) **Retorts.**—The coal is dry-distilled or " carbonised " in these. The retorts are either vertical or horizontal ; we shall only consider the latter, which in cross-section are ⌓-shaped. At each end they are fitted with a door, and they have exit pipes

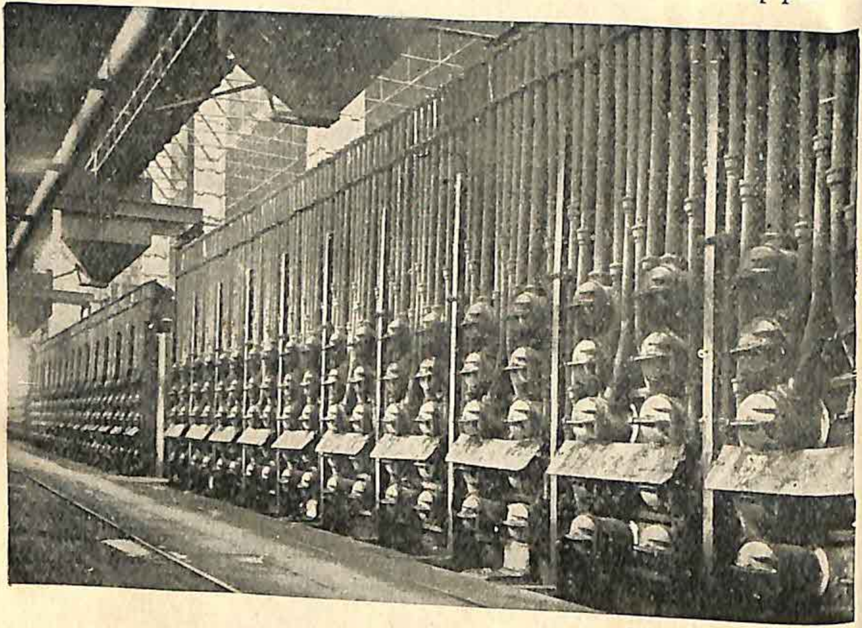


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FIG. 6.—GENERAL VIEW OF RETORTS.

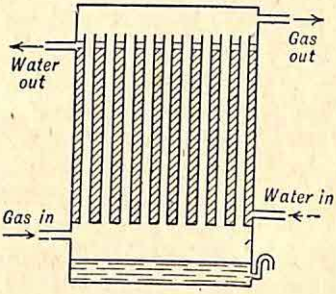
as indicated in Fig. 5. Retorts are of various sizes ; they are made of fire-clay or silica and hold up to 1 ton of coal. As a rule, they are arranged as shown in Fig. 6 ; each group of 10 retorts is set in a separate bay and heated to a temperature of over 1,000° C. by burning producer-gas. This is made in a special furnace below the retorts. In a large works as many as 300 retorts will be found in an installation.

The coal is heated in the large retorts for 12 hours. One of the doors is then opened and the remaining gas ignited ; this operation is carried out for several retorts. The other door is then opened on each of these retorts, then by means of a kind of ramrod from a special machine, which can be manipulated alongside, the red-hot coke is pushed out. This is either fed into the producer-gas furnace or quenched and conveyed to the yard.

After discharging several retorts, the same machine weighs out and " throws " the required weight of coal into the empty retorts in turn, the doors on the opposite side having first been closed. The near door is closed as soon as the charge has been put in, an operation which only takes a minute or so for each retort, and so the carbonisation of the coal proceeds.

(2) **Hydraulic main.**—The exit pipes from the ends of all the retorts pass up to a large pipe which runs horizontally over the bench of retorts ; this large pipe is the hydraulic main. It serves (*a*) to collect the crude gas, (*b*) to cool the gas to a certain extent, and (*c*) as a trap, when the retorts are opened.

(3) **Condensers or coolers.**—The hot impure gas next passes through some form of condenser ; Fig. 7 illustrates a modern, water-cooled type. As the gas passes up through the vertical tubes, it is cooled by the surrounding water. Certain vapours condense and the resulting liquids trickle down and collect in the bottom compartment of the apparatus. The liquids run off to the tar well and separate into (*a*) ammoniacal or gas-liquor, and (*b*) coal-tar.



CONDENSER.

FIG. 7.

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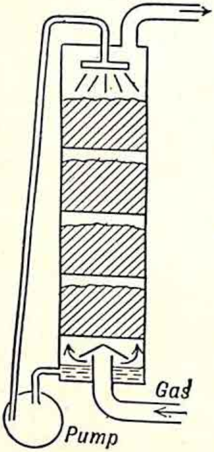


SCRUBBER.

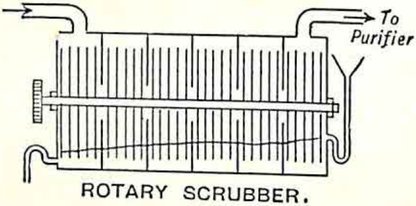
FIG. 8.

The next piece of the plant is a kind of "pump" which draws the gas along to this stage and pushes it through the rest of the system.

(4) **Scrubbers or washers.**—The gas is still not fit for use, and it is next washed in scrubbers. These may be towers packed with coke or planks of wood; the gas passes up the towers, water being sprayed in at the top to trickle down the packing material (Fig. 8).

Rotary scrubbers (Fig. 9) are more efficient; in these, discs are rotated within compartments. The discs are kept wet as they revolve through the washing liquid, and the gas has to pass over their wet surfaces.

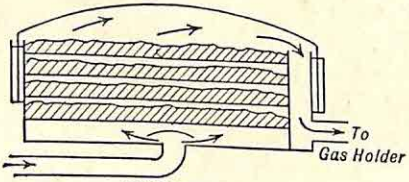
The scrubbers remove soluble gases, especially ammonia and hydrogen sulphide. The liquor from the scrubbers is added to the gas-liquor.



ROTARY SCRUBBER.

FIG. 9.

(5) **Purifiers.**—The gas still contains some hydrogen sulphide, H_2S, and gas companies are compelled by law to remove it. The reason for this is that hydrogen sulphide burns giving sulphur dioxide, an objectionable and poisonous gas. The purifiers are large iron boxes (Fig. 10) containing layers of iron oxide with which hydrogen sulphide reacts to form iron sulphide.



PURIFIER.

FIG. 10.

In a modern works, the gas is next dried by passing it through a scrubber containing a strong solution of calcium chloride ; it is then washed with oil to extract benzene vapour. Finally, the gas is collected in some form of holder (gasometer) over a layer of oil, floating on water.

One ton of coal gives an approximate yield of 12,000 cu. ft. of gas.

Some important by-products of the gas industry

When the coal has been "carbonised," the residue in the retorts is **coke.** Much of this is used in the gas works for making (*a*) producer-gas to heat the retorts, and (*b*) water-gas (p. 4) to mix with the genuine coal-gas. A good deal of the coke is carefully graded and sold as a fuel for household hot-water boilers.

Gas-liquor from the condensers and scrubbers contains about 2 per cent. of **ammonia** ; this is not so valuable as formerly, owing to the manufacture of ammonia from nitrogen and hydrogen. However, the ammonia is extracted by heating the gas-liquor mixed with slaked lime ; it is converted into ammonium sulphate or chloride (Book II, p. 16).

Coal-tar is a very complex mixture from which many important substances are extracted. The coal-tar is distilled, fractions being collected over certain temperature ranges. These fractions on re-distillation and chemical treatment give, among many others, the following substances.

Benzene or benzol, C_6H_6—used in motor spirit ; for making aniline (p. 59), which is converted into dyes and drugs.

Toluene or toluol, $C_6H_5.CH_3$—for making T.N.T. (p. 60) and flavouring substances, e.g. almond essence.

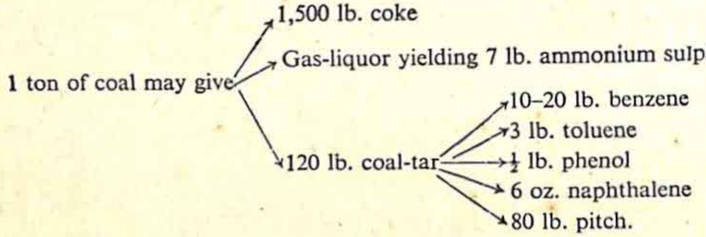
Phenol or carbolic acid, $C_6H_5.OH$—for making picric acid (p. 60) ; dyes and drugs, e.g. aspirin.

Naphthalene, $C_{10}H_8$—for moth-balls, firelighters, and for the manufacture of dyes, e.g. indigo.

Creosote—for preserving wood, e.g. railway sleepers.

Tars—for spraying roads and waterproofing felt.

Pitch—the black substance used as an insulator, e.g. on the tops of dry batteries.



The iron sulphide from the purifiers, when exposed to the air, changes back into iron oxide, **sulphur** being set free. The iron oxide is used several times in the purification of gas, but eventually when the proportion of sulphur is high enough, it is used in the manufacture of sulphuric acid (p. 179).

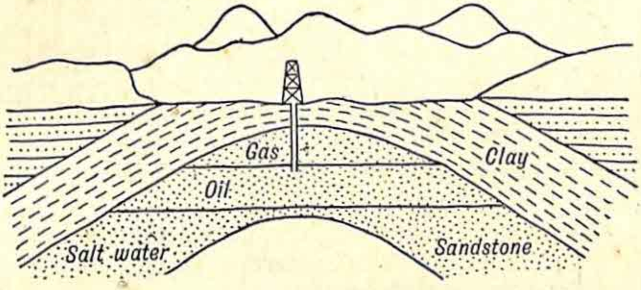
Petroleum

Methane is the simplest member of a closely related family of hydrocarbons called **paraffins**, a name which implies that these compounds do not react much with other substances. However, they are substances of importance, for mixtures of different paraffins occur in petrol, paraffin oil, lubricating oils, vaseline and paraffin wax.

These substances are obtained from petroleum, **mineral oil** which is found in the United States, Russia, Rumania, Mexico, Iran, etc. The great importance of this substance may be gauged from the fact that world production is some 200 million tons. The crude oil varies in colour from pale brown to black and it may be as mobile as water or as " thick " as treacle. It also varies in composition, according to the region in which it occurs. The chief constituents of American petroleum, of which there is the largest output, are paraffin hydrocarbons.

It is now generally believed that petroleum has been formed by the decomposition of the remains of animals and plants, within the earth's crust, at high temperatures and pressures. The petroleum or rock-oil is stored in a porous rock, e.g. sandstone, covered by an impervious rock, e.g. shale or clay, which prevents the oil escaping from the rock formation (Fig. 11). As a rule, below the oil the rock contains water, and above the oil there is natural gas.

In boring for oil, the hole is drilled out and lined with steel tubing. On reaching the oil, the liquid may be forced out by gas under great pressure forming a "gusher," it may flow gently, or it may be necessary to pump the oil to the surface.



SECTION OF ROCKS CONTAINING OIL, SHOWING WELL WHICH HAS STRUCK OIL.

FIG. 11.

The oil is transported from the wells by pipelines to refineries. Refining is a distillation process coupled with chemical treatment to remove unwanted impurities.

Petroleum products and their uses

The more important substances obtained from petroleum are :

Petrol.—Motor fuel of various grades ; a solvent for grease and rubber.

White spirit.—A substitute for turpentine ; used in metal polishes.

Paraffin.—For illuminating and heating purposes.

Gas oils.—Fuel for Diesel engines ; used in gas works to enrich the gas.

Lubricating oils.—Of various grades from sewing machine oil to motor engine oil, etc. ; medicinal paraffin.

Paraffin wax.—For candles, jam-pot covers, insulating coverings.

Petroleum jelly, i.e. **vaseline.**—For creams and ointments.

Fuel oil.—For producing steam power on ships, etc.

Asphalts.—For road construction, roofing felt, bituminous paints.

CHAPTER 2

SOME IMPORTANT CARBON COMPOUNDS

In Book I it was pointed out that the number of chemical elements essential for life is very few, the chief ones being oxygen, carbon, hydrogen and nitrogen. We have also learnt that plants feed on relatively simple substances, e.g. carbon dioxide, water, and various salts, such as nitrates and phosphates. On the other hand, animal food consists chiefly of more complex compounds, which are obtained from plants or other animals. We shall now consider the simple chemistry of some of the substances which we need as foodstuffs, so that you will be able to follow the changes which they undergo during digestion (p. 44).

Carbohydrates

We know a very large number of compounds which are composed of the three elements carbon, hydrogen and oxygen. The carbohydrates are amongst them and these all contain the elements hydrogen and oxygen in the proportions found in water. They have the general formula $C_xH_{2n}O_n$, but you must not get the impression that they are compounds of carbon and water; they do not contain water, and the name carbohydrate is a bad one.

Important carbohydrates are grouped as sugars, starches and celluloses. Of the many sugars known we shall only consider glucose (grape sugar), $C_6H_{12}O_6$, and sucrose (cane sugar), $C_{12}H_{22}O_{11}$. We shall not attempt to distinguish between the different kinds of starch or cellulose.

Glucose occurs in grapes and in honey. It is manufactured on a large scale for use in making jam and confectionery, and in the brewing of beer. Glucose is made by boiling some form of starch, e.g. from maize or potatoes, with dilute sulphuric acid under pressure. When the reaction is complete, chalk is added to neutralise the acid; insoluble calcium sulphate is filtered off, and the solution is decolourised by means of animal charcoal. The solution is concentrated in vacuo and left to solidify.

Commercial glucose is a pale brown solid ; like most sugars it tastes sweet, but it is not so sweet as cane sugar.

If a solution of glucose is added gradually to hot Fehling's solution, the deep blue colour of the latter disappears and a red precipitate of cuprous oxide is obtained.

Cane sugar is familiar to all of you. It is found in sugar-beet and the sugar-cane, and occurs in many other plants as a food store. The manufacture from sugar-beet and sugar-cane is a very important industry ; the world's annual consumption of sugar is many millions of tons.

The roots of sugar-beet are washed, sliced and soaked in water, so that the sugar can diffuse out of the plant cells (Book II, p. 18). The sugar-canes are passed between rollers to squeeze out the juice. The resulting liquids are treated with lime and then filtered, after which the liquid is concentrated in vacuo, allowed to cool and the sugar crystallises.

Raw sugar obtained in this way is refined by dissolving in water, filtering through animal charcoal, followed by evaporation in vacuo and crystallisation.

Cane sugar, unlike glucose, does not react with Fehling's solution.

Starch is found in all green plants ; it is one of the main reserve food-materials of plants, being present in the plant cells in small granules. Important sources of starch are potatoes and cereal grains, e.g. rice, wheat and maize. It is a constituent of plant seeds.

In the manufacture of starch from potatoes, after washing, the potatoes are rasped to a pulp in a special machine to break the cell-walls. The pulp is washed on sieves which retain the tissue but allow starch granules to pass. The starch is allowed to settle, and after running off the water, it is dried.

The general formula for starch is $(C_6H_{10}O_5)_n$, where n is a very large unknown number.

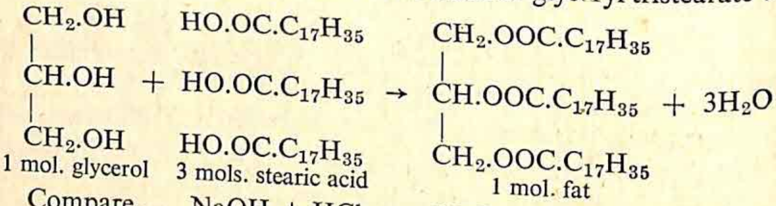
Starch is detected by the deep blue colouration which a solution of it gives with a very dilute solution of iodine (Book II, p. 34).

Cellulose is the chief constituent of the cell-walls of plants ; it is familiar to you all as cotton-wool and filter paper ; it is an essential constituent of wood. Cellulose does not dissolve in water and is not easily digested by most animals.

Fats

These substances are compounds of carbon, hydrogen and oxygen, but their oxygen content is much less than in the case of carbohydrates. We obtain fats from animal tissues by "rendering," i.e. merely heating the tissue or boiling in water as in the extraction of whale-oil, and from seeds of certain plants, e.g. flax (linseed) or cotton, by crushing and heating the ground-up seeds.

These substances may be solid (e.g. beef-fat and mutton-fat) or liquid (oils). Each fat is a kind of salt which is derived from glycerine (glycerol) and an organic acid. Thus, the chief constituent of beef and mutton fats is **tristearin** or glyceryl tristearate :



$$\begin{array}{lllll} CH_2.OH & & HO.OC.C_{17}H_{35} & & CH_2.OOC.C_{17}H_{35} \\ | & & & & | \\ CH.OH & + & HO.OC.C_{17}H_{35} & \rightarrow & CH.OOC.C_{17}H_{35} \quad + \quad 3H_2O \\ | & & & & | \\ CH_2.OH & & HO.OC.C_{17}H_{35} & & CH_2.OOC.C_{17}H_{35} \\ \text{1 mol. glycerol} & & \text{3 mols. stearic acid} & & \text{1 mol. fat} \end{array}$$

Compare , $NaOH + HCl \rightarrow NaCl + H_2O$.

Palm oil is the glycerine salt of palmitic acid, while olive oil is the glycerine salt of oleic acid.

Fats are insoluble in water, but they dissolve readily in ether. If a solution in ether is poured on to a piece of paper, the ether quickly evaporates and leaves a greasy stain. Fats when treated with a 1 per cent. solution of osmic acid become black ; this reaction is used as a test for a fat. The reaction between fats and caustic soda solution to give soap and glycerol is one of great importance (p. 193).

Proteins

These important substances are chemically very complex. They contain the elements carbon, hydrogen, oxygen, nitrogen and sulphur, and often phosphorus. Proteins are an essential part of living matter. They are solids or viscous liquids, which usually coagulate on heating, e.g. white of egg. They react with concentrated nitric acid to give yellow substances, which become orange on the addition of a solution of ammonia. Typical proteins are albumin (white of egg) and casein in milk.

Proteins cannot be made in the laboratory, but we know that they are derived from amino-acids. These substances are organic acids containing an amino-group, $—NH_2$, the simplest being amino-acetic acid, $H_2N.CH_2.CO.OH$.

When proteins are broken down within the living body, they are converted into simpler nitrogen compounds for excretion. Thus, animals excrete urea, $CO(NH_2)_2$, in urine.

CHAPTER 3

CARBON ASSIMILATION AND THE CARBON CYCLE

Chemical compounds in green plants

Protoplasm, the living material of plants and animals, consists chemically of a number of proteins. Water and salts must be present, or the protoplasm dies. Plants and animals also contain reserves of carbohydrates and fats, which are used as fuels (p. 34). Large quantities of them are often accumulated in special storage organs, such as bulbs or tubers, while seeds contain them as food for the plant on germination.

We have seen already that proteins, carbohydrates and fats are relatively complicated compounds of carbon. A plant does not, however, need to obtain these substances ready made. About the year 1620, a Brussels doctor, J. B. van Helmont, planted a willow cutting weighing 5 lb. in 200 lb. of dry earth. He watered the soil for 5 years, at the end of which he had a tree weighing over 169 lb., while the soil weighed only 2 oz. less than before. Van Helmont concluded that 164 lb. of tree had been formed from water alone. His conclusion was wrong, since he forgot that the air, which surrounded the tree, might also play a part. The lost 2 oz. probably represented salts which had been taken up from the soil by the plant. Van Helmont's tree had made the complicated compounds, of which it was composed, from air, water and salts.

The source of carbon in a plant

Cucumbers, tomatoes and many flowers are now grown for market in solutions of salts. Wire baskets, glass wool, granite chips or sand are substituted for soil as supports for the plant. No carbon is needed in these solutions, so the carbon of the plant must come from the air, presumably from the carbon dioxide. Joseph Priestley, one of the discoverers of oxygen, showed that this was true by an experiment which we can easily imitate.[1]

Expt. 1.—*To show that a green plant takes up carbon dioxide.*

Carefully dig up a plantain, and wash the soil from its roots with a gentle stream of water. Place it in a conical flask containing water, and stand the flask on a sheet of glass (Fig. 12). Stand a candle by the side and cover the two with a greased bell-jar. Remove the stopper from the bell-jar, light the candle, and replace the stopper. Describe and explain what happens.

When the candle has finished burning, stand the whole apparatus in as bright sunlight as possible for 5–6 hours. (If it is impossible to finish the experiment during 1 day the apparatus should stand in the light for 2 hours at least before continuing the experiment on a later day.) Light a taper, remove the stopper and relight the candle, replacing the stopper as soon as possible.

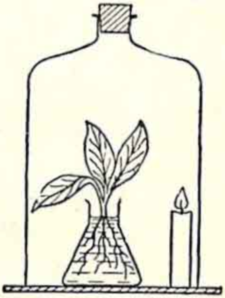


Fig. 12.

The experiment shows us that the plant took up the carbon dioxide which was produced by the burning candle, and replaced it by oxygen. The disappearance of the carbon dioxide can also be shown in the following manner, using a water plant.

Expt. 2.—*To show that a green water plant takes up carbon dioxide.*

Place 40 c.c. of distilled water in a boiling-tube, add 15–20 drops of brom-thymol-blue[2] solution, and the minimum amount of lime-water needed to turn the solution blue. Bubble carbon dioxide (or expired air) through the solution until the colour turns green. Place half the solution in one test-tube, cork well and leave as a control. In the other, place a piece of a water plant,[3] cork well, and place the two tubes in a good light for several hours. At the end of this time compare the liquids in the two tubes and account for any colour changes which have occurred.

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[1] The experiments in this chapter should be carried out on bright days in spring, with vigorously growing plants.

[2] The brom-thymol-blue solution is prepared by dissolving 0·1 gm. of the solid in 100 c.c. of a mixture of 1 vol. alcohol and 4 vols. water.

[3] Elodea, cladophora, starwort, pondweeds.

In Expt. 2 the effect of the green plant is to turn the bromthymol-blue back to the colour which was present before the addition of carbon dioxide. The plant removed carbon dioxide from the water. In Expt. 1 the plant removed carbon dioxide which was produced by the burning candle, and replaced it by oxygen.

Is air the only source of plant carbon?

Although the proportion of carbon dioxide in the air is small (0·03 per cent.) calculation shows that it is adequate for the purposes of vegetable life. A tree, of *dry* weight 5 tons, needs $\frac{1}{300}$ cubic mile of air to supply the necessary carbon dioxide. During the life of the tree it would easily come in contact with more than this amount.

Where is starch made?

The commonest food reserve of plants is the carbohydrate starch. Its formula $(C_6H_{10}O_5)_n$ suggests that it might be made from water and the carbon which the plant obtains from atmospheric carbon dioxide (p. 19). The question at once arises as to which part of the plant makes the starch. Earlier work has given us the following clues:

(*a*) Water rises from the roots, up the stem and into the leaves.
(*b*) Leaves have small pores, the stomata, by which carbon dioxide could easily enter.

In view of these facts we are led to believe that starch is made in the leaves. If this is so, we ought to be able to find it there by applying the usual test for starch (p. 15). However, if we applied the test directly to a green leaf, the colour due to starch would not be seen. Fortunately, **chlorophyll**, which is the green pigment in the leaf, can be removed by means of methylated spirits, and the starch test can then be applied.

EXPT. 3.—*To test for starch in a leaf.*

Take a young leaf[1] from a plant which has been in bright sunshine for 2–3 hours and immediately kill it by immersion for half a minute in boiling water. To decolourise, cover the leaf with alcohol in a beaker and warm cautiously. When the green has been removed soften the leaf by dipping it into hot water, and tear it in two, keeping one half for comparison. Cover the other half with a pale straw-coloured solution of iodine in potassium iodide. If a blue colour does not appear quickly, wait for 10 minutes, wash the leaf and compare with the other half.

---

[1] The leaf should be soft. Plantain and geranium are suitable. Hard leaves (laurel) are decolourised slowly. Leaves of monocotyledons (onion, iris, grass) do not usually make starch.

The formation of starch

Expt. 3 succeeds only when the leaves are taken from a plant which has been exposed to light for some time. This suggests that light is necessary for starch formation. We have already learned that water and carbon dioxide are probably the substances from which starch is made. If, however, we have a solution of carbon dioxide in water, and keep it in the light, starch is not formed. Starch is only made by a *green* plant, and we therefore enquire whether chlorophyll is necessary for the process.

We can test by experiment whether light, chlorophyll and carbon dioxide are essential for starch formation, but we cannot deprive a leaf of water without killing it.

EXPT. 4.—*Is light necessary in starch formation?*

Use a fuchsia plant which has been kept in complete darkness for 48 hours *or* cover the young leaf of an outdoor plant with a completely light-proof envelope for the same period. Black photographic paper is a suitable material for the envelope. After 2 days in darkness cover the selected leaf with a light-proof envelope from which a small square has been cut out to admit light to part of the leaf's upper surface. Fasten closely to the leaf with paper clips, so that light reaches only the small square exposed area, and leave in a bright light for 4 hours. At the end of that time remove the cover and test the whole leaf for starch. What do you find?

EXPT. 5.—*Is chlorophyll essential for starch formation?*

Variegated leaves, such as those of certain kinds of geranium, maple or golden privet, have chlorophyll in the green parts only. Take a variegated leaf which has been exposed to light for some time. Draw the leaf, marking the green areas. Decolourise and test for starch. Do the areas where starch is present correspond to the green areas of the leaf?

EXPT. 6.—*Is carbon dioxide essential for starch formation?*

Choose a plant whose leaves have long stems. Cut a twig with four or five young leaves, stand in water in a conical flask, place the flask in a dark cupboard and leave for 48 hours. After 48 hours take another flask with a very wide neck, or a jam-jar, and a cork with a wide hole. Place 10–15 c.c. of bench caustic soda solution in the flask or jar and shake to bring the liquid in thorough contact with the air in order to absorb carbon dioxide.

Roll one of the leaves of the plant without injuring it, and push it through the hole in the cork. Fill up the hole with cotton-wool soaked in limewater and fit the cork into the flask or jar (Fig. 13). Stand the apparatus in a bright light for 4 hours and then test the eaf in the jar for starch. Test also one of the other leaves. What conclusion can you draw?

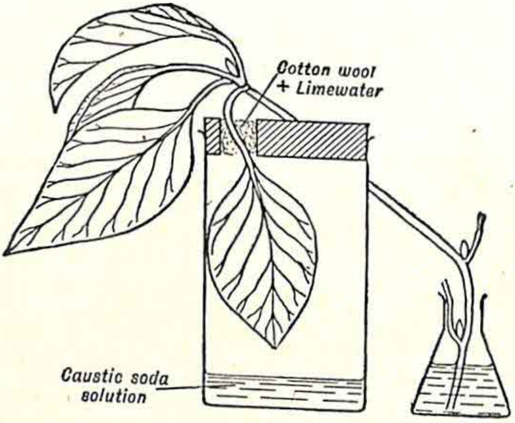

FIG. 13.

The chemistry of starch formation

We have learned that carbon dioxide, water, chlorophyll and light all play a part in the formation of starch. We have reason to believe (Expt. 1) that oxygen is produced in the same process. This can be tested by experiment.

EXPT. 7.—*Is oxygen given off by a green plant in sunlight?*

Fill a 250 c.c. conical flask with water containing calcium bicarbonate (Bristol tap-water serves the purpose well). Now put in the flask some tufts of a water weed (footnote, p. 19). Stand the flask in a trough as shown in Fig. 14 *a*, and expose to sunlight in the open. Bubbles of a gas collect in the weed and carry it to the top of the inverted flask. Shake at intervals to disentangle the bubbles. After several hours transfer the gas to a test-tube, using a deep trough or sink (Fig. 14 *b*). Find whether the gas will rekindle a glowing splint.

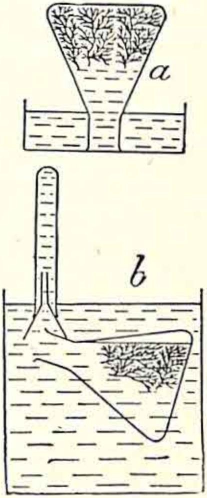

FIG. 14.

The formation of starch can now be represented by an equation :

$$\text{carbon dioxide} + \text{water} \xrightarrow[\text{in presence of light}]{\text{chlorophyll}} \text{starch} + \text{oxygen}.$$

The chlorophyll acts as a catalyst and is therefore not included in the left-hand side of the equation. Since the reaction is one of building up a complex compound with the help of light, the process is known as **photosynthesis.** It is chiefly the red and blue components which are responsible for the process, the green component of the spectrum being largely reflected from the leaf without taking part in photosynthesis. Sunlight is not essential, but is more effective than ordinary sources of artificial light.

We should note that starch is not the first carbohydrate produced during photosynthesis. Experiments show that the sugar, glucose, is first made and then converted into starch. Light is needed only for the production of glucose, which is thus the essential part of photosynthesis :

$$\text{carbon dioxide} + \text{water} \xrightarrow[\text{in presence of light}]{\text{chlorophyll}} \text{glucose} + \text{oxygen},$$

or $$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2.$$

The further change of glucose into starch is a *reversible* one :

$$\text{glucose} - \text{water} \rightleftharpoons \text{starch}.$$

In some plants this does not occur and glucose is stored as a food reserve.

Carbon assimilation

The carbon, which is an essential element in carbohydrates, is derived from the carbon dioxide of the air. Only *green plants* are able to make carbohydrates from this source of carbon, and the process is called **carbon assimilation.** Other substances (e.g. fats and proteins) can then be built up. Animals are unable to make use of the carbon in carbon dioxide and so build up the necessary compounds. Consequently they must get these compounds directly from plants or indirectly by eating other animals or animal products such as butter, cheese or milk. In any case the substances are derived from plants, though they may have undergone minor changes in the body of the cow or other animal involved.

Etiolation

The part played by the light in photosynthesis will be discussed later (p. 113), but it is of interest to note what happens when plants grow in darkness. If two similar seedlings are taken, and one of them transferred to a dark cupboard, marked differences occur in the growth of the two. The one grown in darkness becomes much longer and weaker than the other, while it is much lighter in colour and loses its greenness after some time. It might be described as pale, thin and lanky. In this condition it is said to be **etiolated.**

Sometimes etiolation is put to practical use. The celery grower banks earth round the stems of the plant, or ties them up loosely in paper or cloth. Some kinds of lettuce are also tied up loosely. As a result the inner stems of the celery or the inner parts of the lettuce are obtained in the white or very pale condition that the consumer likes.

The uses of starch in the plant

The conversion of sugar into starch is a reversible chemical reaction. In many (but not all) green plants the sugar produced by photosynthesis is stored as starch in the leaves during the day. At night the starch is reconverted to sugar and carried to other parts of the plant, where it is often once more converted into starch. The sugar is soluble in water and is easily transported in solution, while the starch is insoluble and can be deposited as a solid. The necessary chemical changes are brought about by special types of catalysts, produced in the plant and known as **enzymes** (p. 45).

The starch often goes to form a food reserve in a seed or in a special storage organ, such as a corm, bulb or tuber, in which it is mobilised again as sugar when it is needed. The sugar has two main uses. Some of it reacts with nitrogen compounds which the plant has taken in from the soil. Proteins are formed, and are built up into protoplasm, thus adding to the amount of living material in the plant. The rest of it is used as a fuel (p. 34) to enable the plant to perform the tasks connected with its growth and other life processes.

Barley and malt

The processes which follow the germination of many seeds are examples of the change of starch into sugar. Wheat and barley seeds contain reserves of starch. When the seed germinates the growing seedling produces an enzyme, **diastase**, which converts the insoluble starch into a soluble sugar, to be used as food for the seedling. This particular sugar is called malt sugar since it occurs in malt.

To prepare malt, barley grains are soaked and kept warm and moist. The grains sprout, producing diastase, which begins the conversion of starch into malt sugar. When sufficient diastase has been formed the grains are carefully heated to a temperature which kills the barley plant without destroying the diastase. The product, **malt**, is then kept in hot water to allow the change of starch into malt sugar to continue.

The conversion of starch into malt sugar by means of an enzyme present in our own bodies is described on p. 45.

The carbon cycle in nature

The proportion of carbon dioxide in the air has not changed appreciably during the period in which analyses have been made, yet photosynthesis is going on at a rate which would remove all the carbon dioxide from the air in 30–40 years unless the gas was being replenished in some way. There must be means of balancing this loss.

(*a*) The respiration of plants restores a little of it, while the respiration of animals restores some more, since the animals got their food directly or indirectly by eating plants (p. 24).

(*b*) When plants or animals die, their bodies form the food of innumerable small organisms in the soil. It has been estimated that there are at least two thousand million organisms in 1 grm. of soil. Some of them are dead, others alive, but ultimately they restore to the air the carbon dioxide which was previously taken from it. We call these processes decay, but it is necessary to remember that they restore to circulation carbon dioxide and other substances which would otherwise be locked up uselessly in the dead bodies of plants and animals.

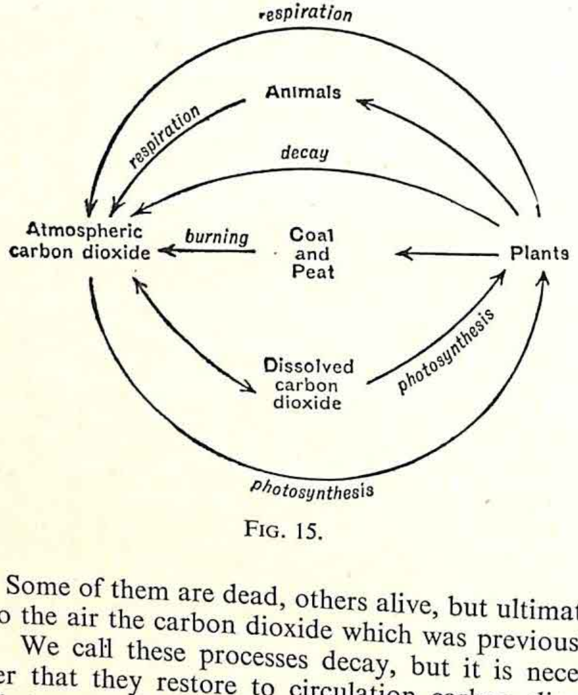
respiration
Animals
respiration
decay
Atmospheric carbon dioxide
burning
Coal and Peat
Plants
photosynthesis
Dissolved carbon dioxide
photosynthesis

FIG. 15.

(*c*) The burning of fuels produces carbon dioxide. Coal and peat came from plants, and the carbon dioxide which was taken from the air millions of years ago is now being restored.

Finally it should be remembered that four-fifths of the earth's surface is covered with water. This dissolves carbon dioxide, some of which is used by water plants. On the whole, however, the seas act as balancers, and dissolve more carbon dioxide when the proportion of the gas in the air rises, giving it out again if the proportion in the air falls.

This circulation of carbon from the bodies of plants and animals into the air and back again, is called the **carbon cycle.** It can be represented diagrammatically as in Fig. 15.

CHAPTER 4

HEAT MEASUREMENTS

What we have learned before

In Book I, Chap. 19, we investigated the means by which a *quantity of heat* could be measured and decided upon the following units :

(1) The quantity of heat which will raise the temperature of 1 grm. of water by 1° C. is called a calorie.

(2) The quantity of heat which will raise the temperature of 1 lb. of water by 1° F. is called a British Thermal Unit (B.Th.U.).

Thus if 200 grm. of water are heated *through* 50° C. (e.g. from 15° C. to 65° C.), $200 \times 50 = 10{,}000$ calories of heat must be supplied. If the weight of water is in lb. and the temperature rise in degrees F., the product gives the heat supplied in British Thermal Units. Similarly, if water cools, the number of heat units given out is equal to the weight of water multiplied by the temperature fall.

When we investigated the heating of substances other than water we found that **a different quantity of heat is required to raise the temperature of 1 grm. of each different substance by 1° C.** This quantity was always less than 1 calorie.

We also found that **when a substance changes its state,** e.g. ice melting, steam condensing, **heat was absorbed or released without changing the temperature of the substance.** We called this heat "latent heat."

In this chapter we shall learn further methods of making heat measurements and some new facts about the results.

The basis of heat measurement

EXPT. 1.—*To study the effect of mixing* (*a*) *equal,* (*b*) *unequal, quantities of hot and cold water.*

Apparatus : Two litre cans, C. thermometer, measuring cylinder, Bunsen burner, tripod and gauze.

Measure out 400 c.c. of water into each can. Take the temperature of one portion. Heat the other portion until its temperature is 55°–60° C. Remove the can from the tripod, stir the water and take its exact temperature. Quickly pour the hot water into the cold water, stir until the temperature of the mixture is fairly steady and then record it. The *weights* of water used are known from the measured volumes. Calculate (*a*) the number of calories lost by the hot water, (*b*) the number of calories gained by the cold water, and compare the results. Repeat the experiment with unequal quantities of water.

We find that, in both cases, the number of calories lost by the hot water is *slightly* more than that gained by the cold water. Further consideration shows that the can itself gained a little heat, for it, too, rose in temperature, and that a little heat was taken up by the neighbouring air. If all gains and losses of heat are considered, **heat gains equal heat losses.**

In all experiments and problems in this book concerning the mixing of a hot substance with a cold substance we shall neglect the extra heat gained or lost by any containing vessel and by the air, and assume that HEAT LOST BY THE HOT SUBSTANCE EQUALS HEAT GAINED BY THE COLD SUBSTANCE.

Some simple problems

Problem 1.—*How much water at* 47° *C. must be added to* 60 *grm. of water at* 12° *C. so that the temperature of the mixture shall be* 32° *C.?*

Heat is gained by the cold water.	Heat is lost by the warm water.
Weight $=60$ grm.	Let Weight $=x$ grm.
Temp. rise $=20°$ C.	Temp. fall $=15°$ C.
Cals. gained $=1{,}200$	Cals. lost $=15x$

Heat gained = Heat lost

$$\therefore 1{,}200=15x$$

$$\therefore x=80 \text{ grm.}$$

Problem 2.—*Find the resulting temperature when* 50 *grm. of water at* 15° *C. are mixed with* 70 *grm. water at* 51° *C.*

Let $t°$ C. be the resulting temperature.

Heat is gained by the cold water.	Heat is lost by the warm water.
Weight $=50$ grm.	Weight $=70$ grm.
Temp. rise $=(t-15)°$ C.	Temp. fall $=(51-t)°$ C.
Cals. gained $=50(t-15)$	Cals. lost $=70(51-t)$

Heat gained = Heat lost

$$\therefore 50(t-15)=70(51-t)$$

$$\therefore t=36° \text{ C.}$$

Capacity for heat

We already know, from Book I, that equal weights of different substances require different quantities of heat to raise their temperatures by 1° C., or, if each receives the same quantity of heat, the rises of temperature will be different. The following experiment revises this fact.

Expt. A.—To compare the thermal capacities of equal weights of water and turpentine.

Apparatus : Vacuum flask provided with a heating coil [1] and thermometer, 15 volts supply, rheostat, key, ammeter, compression spring balance, turpentine, clock.

The circuit is arranged as in Fig. 16 and a current of about 1 amp. arranged. The flask is nearly filled with turpentine and the weight of the latter determined. The temperature is recorded, the current switched on and the time noted. The liquid is gently swilled in the flask during the experiment. After 10 minutes the current is switched off and the final temperature recorded. The temperature rise is evaluated. The turpentine is then replaced by an equal *weight* of water,[2] and, *without altering the current*, the experiment repeated *for the same time*. The temperature rise of the water is evaluated.

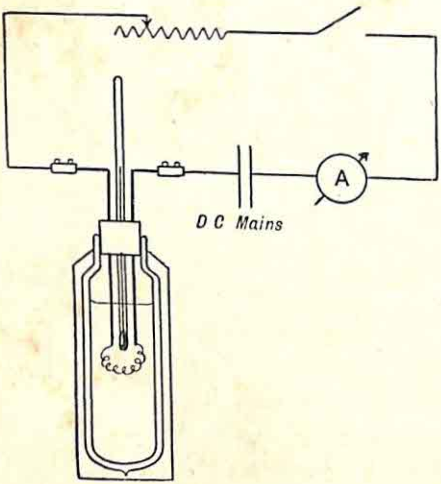

FIG. 16.

By using the same electrical supply for the same time we have supplied equal quantities of heat to equal weights of turpentine and water. The rise in temperature of the turpentine exceeded that of the water. We conclude that, weight for weight, water has the greater **capacity for heat** for it does not get so hot as the same weight of turpentine when supplied with the same quantity of heat.

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[1] For details, see Book II, p. 59.

[2] This must be sufficient to immerse the coil completely.

We define the thermal capacity of a body as the number of heat units (calories or B.Th.U.) which will raise the temperature of the body by one degree. Thus the thermal capacity of 50 grm. of water is 50 calories, of 100 grm. of water 100 calories, but of 100 grm. of turpentine 42 calories.

Specific heat

To form an accurate comparison of the thermal capacities of various substances we must compare the thermal capacity of the substance provided with that of an *equal* weight of a standard substance such as *water*. The fraction so obtained is called the **specific heat** of the substance. Thus, by considering the thermal capacities of 100 grm. each of turpentine and water, we state that the specific heat of turpentine is $\frac{42}{100}$, i.e. 0·42.

We can, however, interpret this figure in a different way. For, 0·42 calories raise the temperature of 1 grm. of turpentine by 1° C.; 0·42 B.Th.U. raise the temperature of 1 lb. of turpentine by 1° F. The specific heat of a substance is thus more *conveniently* described as *the quantity of heat* (*in calories or B.Th.U.*) *required to raise the temperature of unit weight* (1 *grm. or* 1 *lb.*) *of the substance by one degree* (*C. or F.*). A table of specific heats of common substances is given in the Appendix, p. 236.

Clearly, to heat 20 grm. of turpentine through 1° C. would require $20 \times 0{\cdot}42$ calories; to heat 20 grm. through 10° C. would require $20 \times 0{\cdot}42 \times 10$ calories, i.e. **heat required to raise the temperature of the substance = weight × specific heat × temperature rise.** Similarly, if a body cools, **heat loss = weight × specific heat × temperature fall.**

Measurement of specific heats

The specific heats of most solids and liquids can be determined by the "method of mixtures." A hot substance and a cold substance, one of which should be a liquid, are brought together, and if the specific heat of one is known, that of the other may be determined by making the appropriate measurements of weights and temperatures and equating heat losses to heat gains.

The vessel in which the mixing is made is called a **calorimeter.** Its chief feature is the provision of a surround of badly conducting material so that loss of heat to the neighbouring air is as small as possible. A convenient calorimeter consists of a thin copper can loosely fitted with a felt jacket. It is provided with a thermometer and thick wire stirrer, but it is possible to use the thermometer as a stirrer if reasonable care is taken. For some experiments a vacuum flask may be used as a calorimeter.

It is immaterial which substance is the hot one. The following experiments illustrate two common methods. It should be noted that as heat gained or lost by the calorimeter is ignored in this book, *the thermal capacity of the calorimeter must be small compared with that of its original contents.*

EXPT. 2.—*To determine the specific heat of copper* [1] (*first method*).

Apparatus : Calorimeter, thermometer, copper rivets or turnings, boiling-tube, cotton-wool, compression spring balance, pipette, can, stand, Bunsen burner, tripod and gauze.

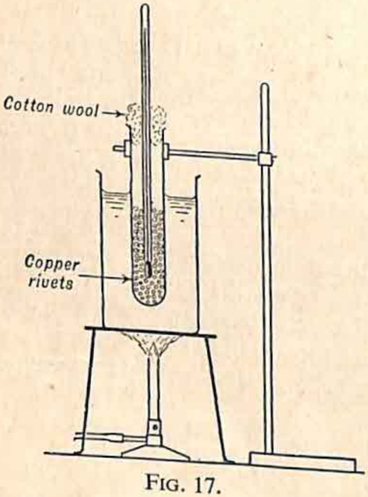

FIG. 17.

Weigh out sufficient rivets to make the boiling-tube rather more than half full. Support the tube and rivets in a can of water, insert the thermometer, and loosely plug the top of the tube with cotton-wool (Fig. 17). Boil the water until the rivets attain a steady temperature and record the reading. Meanwhile measure water into the calorimeter to make it three-quarters full. Take its temperature. Quickly transfer the rivets to the water, stir until the temperature is steady and record it.

Calculate the heat gained by the water and equate it to an expression for the heat lost by the copper. (*The specific heat of copper is the unknown.*) Evaluate the specific heat. Questions: (1) What error is involved in transferring the rivets to the water? (2) What further error would be involved if, instead of heating rivets in a tube, a lump of copper were used and heated by suspension in the water?

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[1] Iron (tacks) is an alternative.

This method can readily be modified to determine the specific heat of a liquid, e.g. turpentine, if the specific heat of copper is known.

EXPT. 3.—*To determine the specific heat of copper* (*second method*).

Apparatus: Vacuum flask (to be used as a calorimeter), copper cylinder with hook (as large as can conveniently be immersed in water in the flask), $\frac{1}{5}$° C. thermometer, graduated cylinder, spring balance, beaker, Bunsen burner, tripod and gauze.

Weigh the copper cylinder. Place it in the flask and add water from the graduated cylinder until the copper is covered. Transfer an equal weight of water to the beaker and warm gently to 50°–55° C. Meanwhile empty and drain the flask; then pour in the warm water. Place the copper cylinder in a tank of cold water to take its temperature. Then take the temperature of the warm water, lift the cylinder and shake off surplus water and gently lower it into the flask. Replace the cork, swill very gently and take the final temperature of the "mixture."

Calculate the heat lost by the warm water and equate to an expression for the heat gained by the copper. Evaluate the specific heat. Questions: (1) Which measurements must be taken with the greatest care? (2) Why was a *large* copper cylinder used?

Some more problems

Problem 1.—*An iron saucepan* (*specific heat* 0·113) *weighing* 1 *lb. contains* 3 *lb. of water at* 60° *F. If both are heated to* 212° *F. in* 5 *minutes, at what rate must heat pass into them?*

Heat gained by water $=3\times(212-60)=456$ B.Th.U.
Heat gained by saucepan $=1\times0{\cdot}113\times(212-60)=17$ B.Th.U.

$\therefore$ Quantity of heat supplied $=473$ B.Th.U.

$\therefore$ Rate of supply of heat $=473\div5=94{\cdot}6$ B.Th.U. per min.

Would the actual rate of supply be more or less than this? Why?

Problem 2.—*When* 80 *grm. of copper at* 100° *C. are added to* 100 *grm. alcohol at* 16° *C. the resulting temperature is* 25° *C. If the specific heat of copper is* 0·093, *what is that of alcohol?*

Heat is gained by the alcohol.	Heat is lost by the copper.
Weight $=100$ grm.	Weight $=80$ grm.
Temp. rise $=9°$ C.	Temp. fall $=75°$ C.
Let its specific heat $=S$	Specific heat $=0{\cdot}093$
$\therefore$ Calories gained $=900S$	$\therefore$ Calories lost $=80\times0{\cdot}093\times75$

$$\text{Heat gained} = \text{Heat lost}$$

$$\therefore 900S = 80\times0{\cdot}093\times75$$

$$\therefore S = \frac{80\times0{\cdot}093\times75}{900} = 0{\cdot}62$$

Calorific value of fuels

Fuels, such as coal and oil, and, very often, coal-gas, are bought for their heating power, and it is important to an industrial consumer to know the number of heat units which a given quantity of fuel will provide. The **calorific values** are determined by burning samples of the fuels in specially designed calorimeters. The value for coal is 10,000–14,000 B.Th.U. per lb., and for fuel oil 17,000–19,000 B.Th.U. per lb. The appropriate value for coal-gas is stated on the bill. In Bristol it is 480 B.Th.U. per cu. ft. of gas, or, as it is alternatively quoted, 4·8 **therms** per 1,000 cu. ft. A therm is 100,000 B.Th.U. and we pay at a stated price per therm.

Foods as fuels

Carbohydrates and fats are used in the body as fuels. Proteins may also be used for this purpose, but that is not their only function. Carbohydrates and fats produce the same quantity of heat when they are slowly oxidised in the body as when they are burned, and their calorific values can hence be found by calorimeter experiments.

The calorific values of foods are expressed in Kilocalories[1] (1 Kilocalorie=1,000 calories). As body fuels, 1 lb. of fat gives just over 4,000 Kilocalories and 1 lb. of carbohydrate or protein gives about 1,800 Kilocalories. Most foods, however, are mixtures of two and often all three of these fuels, and also contain high percentages of water (p. 41). The calorific values of a few important foodstuffs are shown in the following table :

---

[1] Also known as large or great Calories and written with a capital C.

Foodstuff	Kilocalories, per lb.	Foodstuff	Kilocalories, per lb.
Bread (white) . .	1,200	Lean beef . .	600
Potatoes . . .	350	Herring . . .	600
Sugar	1,800	Bacon	2,400
Milk	370 (per pint)	Butter	3,400

Latent heat

That heat is absorbed without change of temperature when a solid changes to a liquid, and a liquid to a vapour, and released during the reverse changes, was discovered by Dr. Joseph Black (1728–99). Being puzzled by the slowness with which ice turned to water, and water to steam, he made measurements of the quantity of heat absorbed during these changes and so discovered the correct explanation.

In order to state the quantity of heat absorbed or released during a change of state, the weight of substance under consideration must be specified. It is usual to refer to unit weight (i.e. 1 grm. or 1 lb.) of the substance, and, therefore, the value of a latent heat is stated in calories per grm. or B.Th.U. per lb.

The latent heat of fusion (i.e. melting) of a substance is the number of heat units required to convert unit weight of the solid into liquid without change of temperature.

The latent heat of vaporisation of a substance is the number of heat units required to convert unit weight of the liquid into vapour without change of temperature.

If unit weight of vapour changes to liquid, or of liquid to solid, the corresponding number of heat units is released.

The latent heat of fusion of ice

Expt. B.—To measure the latent heat of fusion of ice.

A hole, about 1½ in. diameter and 2 in. deep is made, by means of a hot lump of metal, in a large block of ice. A flat slab of ice is used to cover the hole. Such a piece of apparatus is called **Black's Ice Calorimeter.**

An iron ball (about 150 grm.), which will conveniently drop into the hole, is weighed and then suspended in a can of boiling water. While the ball is being heated, a dry sponge in an evaporating basin is weighed on a beam balance. When it is judged that the ball has attained the temperature of the boiling water, the hole is wiped dry with a rag, and the ball then quickly transferred to the hole. The slab of ice is placed on top (Fig. 18). After a few minutes the ball has cooled to the temperature of the ice block (0° C.) and the hole contains water from the melted ice. This water is carefully collected in the sponge, excess water being allowed to drip into the basin, and finally the wet sponge and basin weighed.

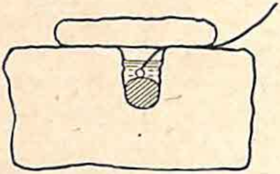


FIG. 18.

How many calories has the ball lost? (Specific heat 0·113.)

How many grams of ice have been melted?

How many calories are absorbed when 1 grm. of ice melts?

Which of the readings taken in this experiment is the least reliable? Explain.

Accurate measurement of the latent heat of fusion of ice shows the value to be 80 calories per grm. (or 144 B.Th.U. per lb.). Thus, *as much heat is required to melt* 1 *grm. of ice as to raise the temperature of the resulting water to* 80° *C.*

Solidification

EXPT. 4.—*To study the cooling and solidification of* (*a*) *naphthalene,* (*b*) *paraffin wax.*[1]

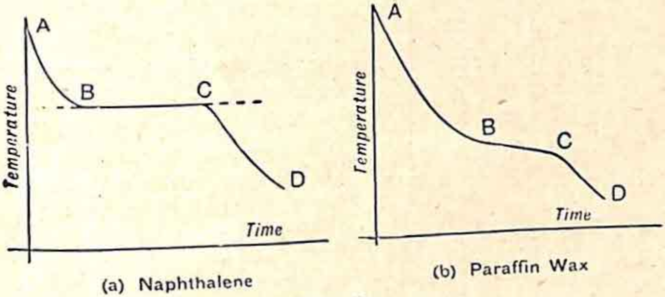
Apparatus: Boiling-tube half full of naphthalene or paraffin wax, thermometer, can, Bunsen burner, tripod, clamp and stand, clock with seconds hand, squared paper.

Support the tube of substance in a can of water and heat until the water is boiling. Place the thermometer in the melted substance and lift the tube, in its clamp, out of the water and well away from the burner. Read the thermometer every ½ minute at first, when the substance is cooling quickly, and later every minute, until the temperature has fallen to about 40° C. Plot a graph on the squared paper of the temperature against the time. What peculiarity does your graph show?

---

[1] It is convenient for each half of the class to study one substance.

Fig. 19 (*a*) shows a graph obtained for naphthalene. The graph is in three parts. AB shows rapid cooling of the molten substance and CD less rapid cooling of the solid. During BC the temperature remains steady for several minutes. At this temperature the naphthalene is solidifying. Why does the temperature not fall, *even though the tube is losing heat to the surrounding air*? This experiment gives a good way of finding the "freezing" point (or melting point) of a substance. What is the melting point of naphthalene?



(a) Naphthalene (b) Paraffin Wax

FIG. 19.

Fig. 19 (*b*) shows a graph obtained for paraffin wax. The middle portion BC has a slight downward slope. The wax, unlike the naphthalene, is a *mixture* of substances and each constituent has a slightly different melting point. The molten wax therefore solidifies over a range of temperature. Determine this range from your graph.

The latent heat of vaporisation of water

EXPT. 5.—*To use a thick-walled calorimeter to determine the latent heat of vaporisation of water.*

Apparatus: Thick-walled brass calorimeter (about 1,000 grm.) with felt jacket, C. thermometer, steam boiler, burette in stand, funnel, compression spring balance.

The calorimeter is fitted with a 2-hole rubber stopper. One hole carries a straight delivery tube and cork to fit the boiler, the other a right-angled exit tube.

Weigh the calorimeter without its accessories and, having replaced the felt jacket, take its temperature. Insert the rubber stopper tightly and, when steam issues *freely* from the boiler, quickly fit on the calorimeter (Fig. 20). When steam issues *vigorously* from the exit tube, wait a further ½ minute approximately and then detach the calorimeter with its accessories. Use the burette (think carefully before you start how you will use it) to find the weight of water formed in the calorimeter.

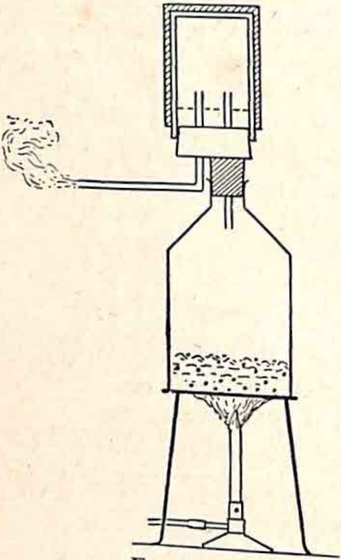


FIG. 20.

What was the final temperature of the calorimeter and its contents ?

How many calories has the calorimeter gained ? (Sp. ht. = 0·092.)

From what did this heat come ?

How many grams of steam condensed ?

How many calories are released when 1 grm. of steam condenses ?

Careful measurements of the latent heat of vaporisation of water show the value to be 536 cals. per grm. (965 B.Th.U. per lb.). This is a comparatively large quantity of heat, and we appreciate now some of the consequences described in Book I (pp. 206–7).

CHAPTER 5

MAN AND HIS FOOD

Why we need food

While we are alive we are never completely at rest. Even during the deepest sleep the heart is pumping blood, and the muscles which carry out our breathing movements are working steadily. The mere act of sitting up increases the work of the heart and other muscles. The process of eating gives work to muscles in the mouth, and later to other parts of the digestive system.

Except in very hot regions we are usually warmer than our surroundings. We are therefore constantly losing heat to them, yet, when healthy, our temperature remains at a fairly constant level.

We grow up from a weight of about 7 lb. to perhaps 10 or 11 stones, a twenty-fold increase. We also partially replace our worn-out parts as we go along, in contrast with mechanical vehicles which occasionally need completely new parts supplied ready-made.

To maintain the body temperature and the activity of the heart and other parts of the body, fuel is needed. This fuel, and the materials for increase in weight and replacement of worn-out parts, come from the food we eat.

In addition to the requirements of food for fuel, growth and replacement, small quantities of other substances are essential as body regulators and protectors. If there are insufficient salts, many essential processes, such as growth of bones or formation of hæmoglobin cannot take place properly, and if the vitamins are insufficient in amount we suffer from unpleasant diseases.

Our fuel requirements

A man's daily output of heat has been measured directly by putting him in a very large calorimeter for a period of 24 hours. He is supplied with a bed, telephone, light and a fan, and provision is made to measure the quantity of heat he produces by methods which are merely modifications of those used in the physics laboratory. This method is useful to give us measurements if the subject is sitting or lying down, or performing some kind of work which can conveniently be performed in the confined space. For work which involves less restricted movements other methods are available.

When a man is oxidising food inside his body, measurements of the volume of oxygen he uses, and the volume of carbon dioxide he produces, make it possible to calculate how much heat he is producing. These measurements can be carried out, even for such exercises as swimming, walking, running or woodcutting. The subject of the experiment breathes in through a valve leading to his nose, and breathes out into a bag. His nose is clipped. The volumes of oxygen, carbon dioxide and nitrogen in the bag are measured after the exercise, and the volume of air used is calculated from the volume of nitrogen in the bag.

As a result of these, and other types of experiment, the quantity of fuel required daily has been ascertained. A man lying down and completely at rest, needs about 1,800 Calories (p. 34) per day. If, during the usual hours, he performs an ordinary day's work, his requirements increase to 3,000–3,500 Calories, while a man such as a woodcutter may need 5,500 or more. You will see why exercise gives an appetite. An athlete in competition, such as a 24-hours cycle race, may have such an enormous requirement for that particular day that he may be unable to eat the necessary quantity of food. In that case he partly lives on his own stores of fat and sugar, and makes up this loss later.

A daily income of about ¼ lb. (dry weight) each of fat and protein, and rather over a pound of carbohydrate, gives about the right weight of fuel and replacement foodstuffs for a man doing work not of a heavy nature.

The kinds of food

Our bodies contain about 70 per cent. by weight of **water**, and we suffer a large daily loss in the various excretions. This must be replaced, so water must be regarded as a foodstuff. If we include the water contained in other foods which we eat, we probably take in a weight of water three times that of the other foodstuffs combined.

Proteins, **fats** and **carbohydrates** constitute the bulk of our food apart from water. They can all be used as fuel foods, but proteins have the additional and important use of tissue building, which overshadows their use as fuel. It is usually regarded as desirable to employ proteins primarily for this purpose, and to make up the bulk of our fuel requirements from the other two. The chief sources of protein are meat, fish, milk, cheese, eggs, peas and beans, while bread contains a useful proportion. The diet should contain a proportion of protein derived from animals or animal products such as milk and eggs, since these contain certain amino-acids not adequately supplied by a vegetarian diet.

Butter, margarine, milk, cheese and the fat in meat, are the chief sources of fats, while the carbohydrate foods include all cereals and cereal products such as bread and the many patent breakfast foods. Sugar is a carbohydrate in pure form.

The following table shows the approximate composition of a few standard foodstuffs:

Food	Approximate percentages				
	Water	Protein	Fat	Carbo-hydrate	Salts
White bread . . .	38	7	1	52	2
Lean meat . . .	72	21	6	0	1
Potatoes	77	2	0	20	1
Milk	87	3	4	5	1
Butter	15	0·2	84·4	0	0·4
Eggs	75	12·5	11·5	0	1

The other foodstuffs are **salts** and **vitamins**. These will be discussed in detail below.

Salts

An animal cannot live healthily on a diet which is free from salts. If it is fed on such a diet it acquires a dislike for food, and soon dies. In order to obtain sufficient salts we need to eat fruits and vegetables. Salts, with the soil water, enter plants through the root-hairs and accumulate since they cannot be lost by transpiration.

The functions of salts in the body are numerous, but a few examples show their necessity. Calcium compounds are needed to form bone, to enable a muscle to contract and to allow blood to clot in order to stop bleeding. Phosphates are needed in bone formation, the hardness of bones being largely due to calcium phosphate, while iron is necessary for the production of hæmoglobin. Perspiration and excretion of water via the kidneys remove salts from the body, requiring their replacement by the food we eat.

Vitamins

In 1593 Sir Richard Hawkins, a British Admiral and contemporary of Drake, said that *from his own experience* he could vouch for the death of 10,000 seamen from scurvy. For centuries this disease afflicted seamen, armies in the field, and even, as in the war of 1914–18, people living in England. It is a disease in which bleeding occurs very freely in the gums, under the skin and into joints. Much pain and weakness are caused, and ultimately death. Hawkins showed that it could be cured by eating oranges, but it is only since 1907 that the nature of the disease has been really understood.

Experiments on guinea-pigs and rats have shown that orange juice contains a substance, now obtainable in pure form, of which minute amounts will prevent or cure scurvy. Scurvy is not infectious, and cannot be " caught " from someone else. It is something which goes wrong with the workings of the body when a certain substance is missing from the diet. The usual name given to this substance is **vitamin C.**

Several other non-infectious diseases are now known to be caused by the lack of particular substances in the diet. They are called *deficiency diseases* and the substances which prevent them are known as **vitamins.** Carefully purified and prepared foods such as white bread, sugar and rice, have had much, if not all, of their natural vitamins removed. It is compulsory by law to add certain vitamins to margarine, and, as a war-time measure, compulsory addition of vitamins and calcium salts to white bread might be necessary. To include an adequate supply of vitamins the diet should contain plenty of vegetables and fresh fruit, eggs, milk, butter or vitaminised margarine, and a weekly meal of fish, preferably herring or salmon.

The following table summarises some facts about the more important vitamins :

Name of vitamin	Effect of deficiency	Good food sources	Moderate food sources
Vitamin A .	Eye inflammation. Night blindness.	Fish liver oils. Butter. Spinach. Egg yolk.	Carrots. Cabbage. Milk.
Vitamin B_1 .	Beri-beri (nervous pain and paralysis).	Wheat germ. Yeast.	Meat. Eggs. Brown bread.
Vitamin B_2 .	Body cells cannot respire properly. Poor growth.	Yeast. Liver.	Milk. Eggs.
Vitamin P.P. .	Skin disease.	Yeast. Liver.	Milk. Eggs. Cheese.
Vitamin C .	Scurvy.	Black currants. Oranges. Lemons.	Fresh fruits and vegetables. Milk.
Vitamin D .	Rickets (bones unable to develop correctly).	Fish liver oils.	Eggs. Butter. Milk.

Vitamin C is easily destroyed by heat, particularly if soda is used in cooking. Vitamins B and C dissolve in water and are largely lost if vegetables are boiled in water and the liquid thrown away.

Milk is a specially valuable food as it is a source of almost all the vitamins, and also of essential salts, particularly of calcium salts and phosphates.

Digestion

Digestion is the process by which the foodstuffs we eat are converted into substances capable of entering the bloodstream and being utilised by the body. Water, salts, glucose and vitamins need no digestion. They are already in the final form in which they are received by the blood. For the following reasons, other foodstuffs need to be changed by the processes of digestion.

(1) Most foodstuffs are insoluble in water. The first process of digestion must be to make them into soluble materials.

(2) Some substances, even when soluble, have large molecules which diffuse too slowly from the digestive system into the blood. Cane sugar is an example.

(3) Changes may be needed in the *nature* of food. Proteins from the cow or from peas are not the same as our own body proteins. We need to break the proteins down to the individual *amino-acids* of which they are composed, and then to rebuild these into our own special kinds of protein.

The process of digestion consists therefore of a series of changes which break down the complex foodstuffs which we eat into more simple ones.

Enzymes

EXPT. 1.—*To illustrate the digestion of starch by saliva.*

Half fill a 750-c.c. beaker with water, warm until the temperature reaches 37° C. and then turn the flame low so that the temperature keeps between 37°–40° C. Rub 0·2 grm. (approx.) of soluble starch to a cream with water, add to 20 c.c. boiling water, and mix. Place the tube of starch solution in the beaker of warm water.

Rinse out the mouth with warm water, take another mouthful, retain it for 1–1½ minutes and discharge it into a boiling-tube. Place this in the large beaker until it and the starch solution have attained a temperature of 37°–40° C. Dilute a solution of iodine in potassium iodide to a pale straw colour by adding water. To a drop of this solution in a test-tube add one or two drops of the starch solution. If no blue colour is obtained a fresh starch solution must be prepared.

Divide the remaining starch solution into two portions, and keep them in the beaker during the rest of the experiment, except when they are momentarily withdrawn for use. Label them A and B. Boil 2–3 c.c. of saliva solution for ½ minute, and add to the starch in A.

Add the same volume of unboiled saliva solution to the starch in B, mix, and at $\frac{1}{4}$-minute intervals withdraw a few drops from B and add to a drop of iodine solution. Continue until no blue colour is obtained on mixing. Now test the tube A of starch and boiled saliva with iodine. Is a blue colour obtained? What do your results show about the following:

(*a*) The action of saliva on starch;
(*b*) The effect of boiling the saliva?

Test the remaining liquid in B with a small quantity of Fehling's solution as described on p. 15. What happens?

The saliva of human beings and other mammals contains a substance, **ptyalin**, which rapidly attacks starch and converts it to malt sugar. This change, the same as occurs in a germinating seedling (p. 25), consists of the addition of water to starch, causing it to break down into simpler molecules:

$$\underset{\text{starch}}{(C_6H_{10}O_5)_n} + n/_2H_2O \rightarrow n/_2\underset{\text{malt sugar}}{C_{12}H_{22}O_{11}}.$$

Ptyalin catalyses the reaction. The other changes during the digestive process are of a similar nature. Complex substances are split into more simple ones by the addition of water, a process called **hydrolysis.** The changes are catalysed by different **enzymes**, of which ptyalin is the first to act.

Enzymes are special catalysts which enable living organisms to bring about the changes needed for their life processes. They are complex *substances* (i.e. not living material) but can be made only by living organisms. Enzymes are only effective—

(1) Within a narrow temperature range, and are destroyed at moderately high temperatures;
(2) In appropriate degrees of acidity or alkalinity.

A given enzyme can only bring about one particular kind of chemical action.

Our digestive system

The digestive system contains two main portions. The first of these is the food canal, consisting of the mouth, pharynx, gullet, stomach, small and large intestines. These form a

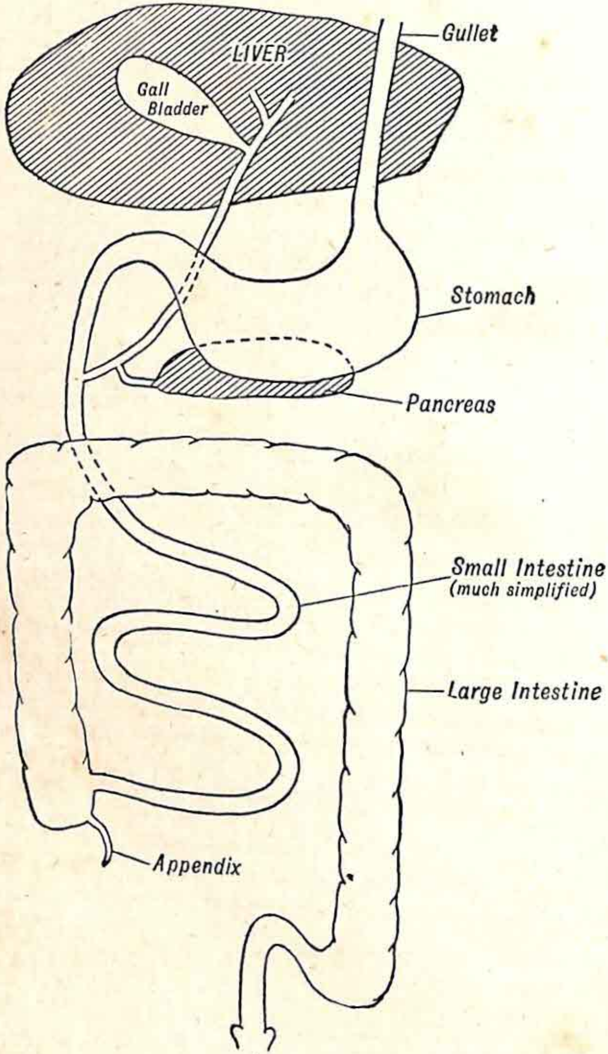

Gullet
LIVER
Gall Bladder
Stomach
Pancreas
Small Intestine
(much simplified)
Large Intestine
Appendix
Anus

FIG. 21.

continuous passage through the body, from the mouth entrance to the anus, or exit from the large intestine (Fig. 21). The second part consists of two organs which, though not forming part of the food canal itself, produce substances from the blood and pass them into the small intestine to help the process of digestion. These organs are the liver and the pancreas. They are large **glands.** A gland is an organ which makes or separates certain substances from the blood.

The **mouth** is supplied with glands which make saliva, and with teeth (Fig. 22) for mechanically dividing the food into small pieces by cutting and grinding.

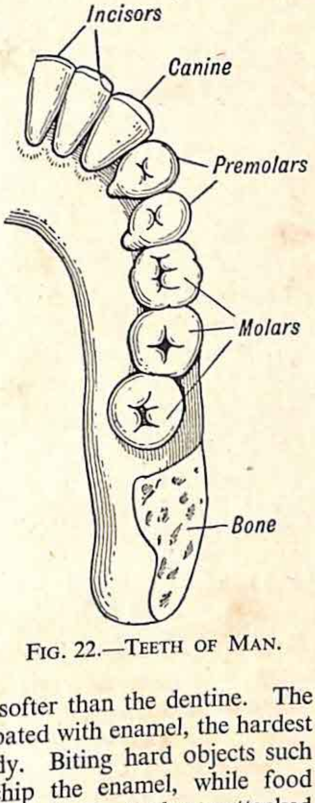
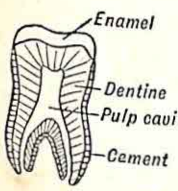


FIG. 22.—TEETH OF MAN.

A tooth (Fig. 23) consists essentially of a mass of hard material, the dentine, surrounding a cavity filled with pulp, a soft material permeated by nerves and blood vessels. The tooth has a root or roots fitting into sockets in the jaw-bone, each root being surrounded by a layer of cement, a material rather softer than the dentine. The crown, or exposed part of the tooth, is coated with enamel, the hardest substance in the body. Biting hard objects such as nuts, tends to chip the enamel, while food particles left in contact with the teeth are attacked by bacteria, forming acids which corrode the enamel and lead to decay of the dentine.



The **pharynx**, or cavity at the back of the mouth, is connected to the **stomach** by means of a muscular tube, the **gullet** (food pipe or œsophagus). The stomach is a bag-like organ with glands and muscular walls. The lower end of the stomach opens into the **small intestine**, a narrow tube, some 20 ft. in length, in which occur the main processes of digestion and absorption.

Its inner walls are heavily folded (Fig. 24) to give a greater surface, and to prevent food from passing along too quickly or too smoothly. In addition the surface is covered with numerous hair-like projections or **villi** (Fig. 25) which increase the absorbing surface enormously. The villi are supplied with blood capillaries and lacteals (p. 50).

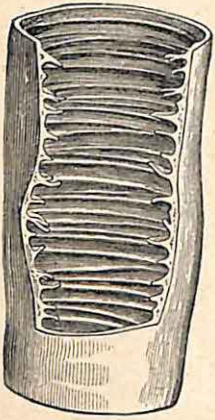


FIG. 24.—FOLDS IN THE WALL OF THE SMALL INTESTINE.

The **large intestine** is a wide tube about 6 ft. long, which leads from the small intestine to the anus. The two intestines together thus make a tube which could be wrapped nine or ten times round the waist. Near the junction of the two, a worm-like projection, the appendix, joins the end of the large intestine. It has no useful function in ourselves, but is concerned with the digestion of cellulose in many grass-eating animals.

The **liver** is the largest gland in the body, weighs about 3½ lb. and contains about one quarter of the blood in the body. Tubes lead from it to a small storage organ, the **gall bladder,** and from this a single tube, the bile duct, leads to the small intestine. The **pancreas** (sweetbread) lies below the stomach and communicates with the small intestine by a tube which enters by the same opening as that from the gall bladder.

All the digestive organs except the mouth, pharynx and upper parts of the gullet lie in the **abdomen** which is a space separated from the chest above it by the diaphragm.

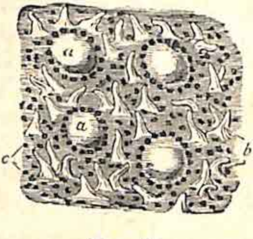


FIG. 25.
a and *c* glands, *b* villi.

The process of digestion

In the mouth food is broken up by the teeth and mixed with saliva. The **ptyalin** begins the *conversion of starch into malt sugar*, but other kinds of food are not changed chemically. The chewed food is forced down the gullet by muscular action, the walls of the gullet contracting behind the food and relaxing in front of it (Fig. 26).

When food reaches the stomach it gathers into a mass, inside which the action of ptyalin on starch continues for some time. Gradually, however, it is broken up by movements of the stomach walls and penetrated by juices from the stomach glands. These liquids, the gastric juices, contain very **dilute hydrochloric acid** and an enzyme, **pepsin**. Pepsin, aided by the acid, *converts proteins into soluble compounds, peptones. Milk is clotted*, thus delaying its stay in the stomach sufficiently for the digestion of the milk proteins.

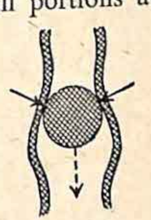


FIG. 26.

After a time the acid and partly digested stomach contents are passed out into the small intestine in small portions at a time. Here they mix with three liquids, pancreatic juice, intestinal juice and bile. The first of these contains enzymes produced by the pancreas, and the second enzymes produced by glands in the walls of the small intestine. Bile comes from the gall bladder, where it accumulates as the liver makes it. It is a greenish or yellowish liquid owing to coloured waste products which it contains. Its usefulness in digestion is due to the fact that it causes fats to form an emulsion of very fine droplets which can be more readily attacked than larger globules. Bile contains no digestive enzymes, and the chemical changes which occur in the small intestine are due to enzymes in the pancreatic and intestinal juices. These changes are as follows :

(1) Fats are converted into fatty acids and glycerine.

(2) Unaltered starch, and sugars, are broken down to glucose.

(3) The digestion of proteins is continued until they are broken down to the individual amino-acids of which they were composed.

The carbohydrate cellulose is not dissolved in the human digestive system, but the other foodstuffs are now in the form needed for absorption.

The absorptive system

Blood capillaries in the walls of the small intestine, and in the villi, unite to form a vein. This vein does not join the general stream of blood returning to the heart, but goes instead to the liver, where it once more divides into capillaries. There is thus a direct route from the intestine to the liver. This special instance, where a vein passes from one organ to another and forms a second capillary system, is known as a **portal** system. The vein is called the portal vein.

In all parts of the body blood minus the red corpuscles is constantly oozing out of the capillaries into the surrounding tissues, to which it carries dissolved nutriment. This fluid, the **lymph**, then collects in a system of tubes and is returned to the blood system by two openings into veins at the base of the neck. Some of these lymph vessels are present in the villi (Fig. 27) where they are called **lacteals**, from the milky appearance of their contents following a meal of fat. The lacteals lead to the larger of the openings by which lymph is returned to the blood.

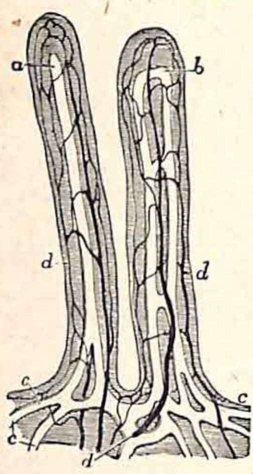


FIG. 27.—TWO VILLI. (*a*), (*b*) and (*c*) lacteals; (*d*) blood vessels.

The absorption and fate of the foodstuffs

The amino-acids from protein digestion and the glucose from carbohydrates are absorbed into the blood capillaries in the walls of the intestine and pass to the liver. The liver acts as inspector or censor of the absorbed food materials. Glucose in excess of immediate body requirements is kept back and stored in the form of glycogen, a starch-like substance. Protein in excess of the body's needs is used as fuel, while the amounts of substances needed by the body are allowed to pass into circulation.

The mixture of glycerine and fatty acids on the other hand is taken up by the lacteals, reforms globules of fat, and passes up to the jugular vein at the base of the neck, where it enters the bloodstream. An excess of fats over bodily fuel requirements is stored for future use under the skin, between the muscle fibres and (sometimes very conspicuously) in the folds of a membrane in the abdomen between the loops of the intestines.

The large intestine

In the small intestine most of the useful food and much water are absorbed into the blood vessels and lacteals. Bacteria, undigested materials and water remain unabsorbed and pass on to the large intestine. In the interests of water economy much of the remaining liquid is here re-absorbed into the blood. If this did not occur, we should have to drink extra liquid to make up for the increased loss.

The large intestine acts as an excretory organ, since insoluble compounds such as calcium phosphate, which might block small tubes in the kidneys, are collected here for removal. They join the mass of undigested material and bacteria which form the contents of the large intestine. This waste accumulates in the end portion, the rectum, and is voided at intervals as the *fæces*. If the intervals are irregular or delayed, undesirable results follow. Poisonous products from the bacteria accumulate and are absorbed into the blood vessels of the intestine. From there they pass into the general circulation, at first causing such minor disorders as headaches or loss of vigour, though later more persistent effects may follow.

CHAPTER 6

NITRIC ACID AND SOME OF ITS DERIVATIVES

Chile saltpetre, sodium nitrate, $NaNO_3$

Large quantities of this salt occur in Peru, Bolivia and Chile. The mineral, called *caliche*, is found in layers a few feet below ground-level. The ground is opened up by boring to the bottom of the bed of mineral and firing a charge of explosive in the bore-hole. The crude mineral is sorted by hand and carted to the works, where the sodium nitrate is extracted with hot water, then crystallised from the resulting solution (Book I, p. 67).

Commercial sodium nitrate is produced in large quantities for use (1) as an artificial manure, (2) for making potassium nitrate (nitre) and nitric acid.

The preparation of nitric acid, HNO_3

Nitric acid is made in the laboratory by heating a mixture of concentrated sulphuric acid and a nitrate, potassium nitrate being used as a rule. The apparatus needed is shown in Fig. 28.

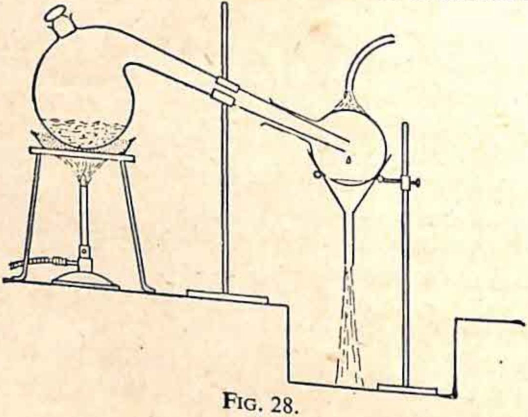


FIG. 28.

The sulphuric acid (30 grm.) is first poured into the retort, then the nitre (25 grm.) is added. After setting up the apparatus as shown, the retort is heated on the sand-bath, at first gently, then quite strongly, while water is allowed to run over the receiving flask. All the apparatus must be glass, since concentrated nitric acid attacks cork and rubber.

The nitre first dissolves, then nitric acid vapour distils, condenses in the neck of the retort and runs down into the receiver. Towards the end of the distillation, as the temperature rises, a brown gas is seen in the retort. Some of this gas dissolves in the nitric acid, which is obtained in the receiving flask as a yellowish, fuming liquid.

When no more acid distils, the stopper is removed from the retort and the contents carefully poured into a large porcelain dish. The liquid quickly sets to a mass of colourless crystals, potassium hydrogen sulphate, $KHSO_4$.

The equation for the production of nitric acid is :

$$KNO_3+H_2SO_4 \rightarrow HNO_3+KHSO_4.$$

The brown gas, nitrogen peroxide, is formed by the decomposition of some of the nitric acid by the action of heat.

The properties of nitric acid

Concentrated nitric acid is a colourless liquid which fumes in damp air ; it has a peculiar odour. The sp. gr. of the acid is about 1·5. The acid mixes with water in any proportions ; the dilute acid has a sour taste, causes blue litmus to become red, and corrodes metals. The concentrated acid is very corrosive ; it attacks the skin, forming a yellow substance (p. 17), and destroys cloth.

The concentrated acid was originally called *aqua fortis*, because it dissolves most metals. When the acid attacks metals, as a rule, a gas is evolved, but the gas is not hydrogen except in the case of magnesium and very dilute acid.

EXPT. 1.—*To investigate the action of nitric acid on copper.*

(*a*) Put a few copper turnings into the flask shown in Fig. 29, then drop concentrated nitric acid into the flask carefully. The copper starts to dissolve at once and a brown gas is given off. Collect a jar full of this gas (do not allow much to escape into the room) and close the jar with a greased plate. Note the colour of the liquid in the flask.

Stand the jar mouth downwards in a trough of water and slide off the plate. You will find that the gas dissolves readily in water. Again close the jar with the plate and remove the jar from the trough. Try the effect of adding (*a*) litmus solution, (*b*) a dilute solution of potassium permanganate containing dilute sulphuric acid, to separate portions of the solution in the jar. What do you see?

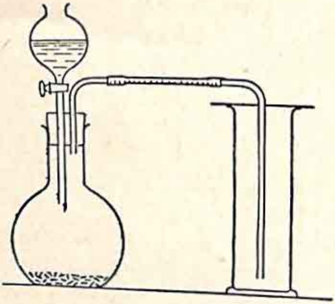


FIG. 29.

(*b*) Put some copper turnings into a flask and set up the apparatus shown in Fig. 2. Mix 15 c.c. concentrated nitric acid and 10 c.c. water, and drop the diluted acid on to the copper. After allowing air to escape from the apparatus, collect a jar of gas. Close the jar with a greased plate and note that the gas is colourless. Hold the jar mouth upwards and slide off the plate. What do you see and infer?

The action of nitric acid on copper

Concentrated nitric acid readily dissolves copper giving a blue solution of copper nitrate and the brown gas, **nitrogen peroxide,** NO_2. This gas readily dissolves in and reacts with water. The resulting solution is acid, and it decolourises purple potassium permanganate solution. This shows that the solution contains nitrous acid, HNO_2; it also contains nitric acid, but there is no simple test to indicate this. The reaction between nitrogen peroxide and cold water is:

$$2NO_2 + H_2O \rightarrow HNO_2 + HNO_3.$$

Somewhat diluted nitric acid also dissolves copper giving copper nitrate as before, but this time the gas evolved can be collected over water. The gas is colourless and insoluble in water; it is **nitric oxide,** NO. On opening a jar of nitric oxide in air, brown nitrogen peroxide is at once formed. Nitric oxide and oxygen combine at fairly low temperatures (below red "heat") to give nitrogen peroxide:

$$2NO + O_2 \rightarrow 2NO_2.$$

The manufacture of nitric acid

Nitric acid is an important chemical and it is made on a large scale by the following two processes :

(1) The old process, still used, is exactly parallel to the laboratory preparation. Sodium nitrate (Chile saltpetre) is heated with concentrated sulphuric acid in cast-iron retorts ; nitric acid vapour is condensed in earthenware or silica pipes and the acid is collected in earthenware jars.

(2) In a much more recent process, the acid is made from ammonia, obtained from nitrogen and hydrogen by the Haber process (Book II, p. 13), and air. The ammonia and air are mixed in certain proportions and the mixture is passed rapidly through a platinum gauze. This gauze is first heated electrically, but once the reaction has started the heat given out in the reaction keeps the gauze red-hot. The platinum acts as a catalyst in the following reaction :

$$4NH_3+5O_2 \rightarrow 4NO+6H_2O.$$

The nitric oxide, on cooling, then reacts with excess oxygen from the air at first admitted and gives nitrogen peroxide.

The mixture of nitrogen peroxide, excess oxygen and nitrogen is passed up granite towers, containing lumps of quartz, down which water trickles. The nitrogen peroxide first reacts with the water to form nitrous and nitric acids :

$$2NO_2+H_2O \rightarrow HNO_2+HNO_3.$$

Under the conditions employed, the nitrous acid decomposes into nitric acid and nitric oxide, thus :

$$3HNO_2 \rightarrow HNO_3+2NO+H_2O.$$

This nitric oxide is reoxidised to nitrogen peroxide, which again reacts with water. The final result is that 30 per cent. nitric acid is obtained. This is either concentrated by distillation with concentrated sulphuric acid, or it is made into calcium nitrate by treating the acid with limestone. The calcium nitrate is sold as an artificial manure called Norwegian saltpetre.

Still more recent practice is to work the whole process under a pressure of a few atmospheres and absorb the gases in a water-cooled, chrome-steel tower. In this way 60 per cent. acid is obtained.

as possible into the flask. The platinum continues to glow in the mixture of ammonia gas and air for a considerable period, but the formation of brown nitrogen peroxide is not readily seen.

Nitrates

The salts of nitric acid are called nitrates ; they all contain the radical (group of atoms) $-NO_3$, valency 1 (see Book II, p. 44). Nitrates can be obtained by

(1) The interaction of nitric acid and a metal ;
(2) Neutralising nitric acid with an alkali ;
(3) The interaction of nitric acid and a metallic oxide (or a carbonate).

Full directions are given for the preparation of potassium nitrate by method (2) in Book II, p. 42. The following experiments illustrate methods (1) and (3).

EXPT. 2.—*To prepare lead nitrate.*

Weigh approximately 3 grm. lead filings and add to 30 c.c. dilute nitric acid (2N.) in a flask. Warm the flask till the lead begins to dissolve ; this is shown by the evolution of a gas. Do not boil, but keep the reaction going by warming the flask at intervals. If the volume of liquid decreases, add a little distilled water. If the liquid becomes yellowish before the lead has dissolved, you have taken too much lead, so add a little more acid. When the lead has dissolved, pour the solution into a dish and evaporate until it begins to deposit a white solid. Then allow the solution to cool. When cold, pour off the liquid remaining and dry the solid between pieces of filter paper. Small, white, sparkling crystals of lead nitrate are obtained.

EXPT. 3.—*To prepare copper nitrate.*

Weigh approximately 4 grm. copper oxide (or 5 grm. copper carbonate) and tip the solid into a beaker. Add about 20 c.c. dilute nitric acid and warm. Gradually add more acid and keep the liquid hot until the solid just dissolves. Evaporate the clear blue solution obtained in this way to a very small volume. Be careful not to decompose the solid copper nitrate by heating too strongly with too large a flame. Leave the blue liquid to cool ; it will set into a crystalline mass of copper nitrate. The reactions are :

$$CuO \quad + 2HNO_3 \rightarrow Cu(NO_3)_2 + H_2O$$
$$CuCO_3 + 2HNO_3 \rightarrow Cu(NO_3)_2 + H_2O + CO_2.$$

The catalytic oxidation of ammonia

The production of nitrogen peroxide from ammonia and air is illustrated by the following experiment. The apparatus shown in Fig. 30 is first set up. Flask B (250 c.c.) contains a few cubic centimetres of 0·880 ammonia solution, and the end of the inlet tube is arranged a little way above the surface of the liquid. Flask B is connected to a hard-glass tube containing some platinised asbestos, which is kept in position by plugs of glass wool. Flask A must be dry; it is connected to a Büchner pump.

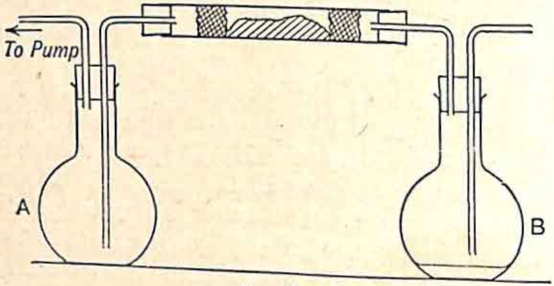


Fig. 30.

The platinised asbestos is heated to a low red heat, the burner removed, then a strong stream of air is drawn through the apparatus by means of the pump. At first the platinum glows brightly and flask A becomes full of white fumes. As the experiment proceeds the glow of the platinum becomes less intense and the white fumes are replaced by brown nitrogen peroxide. Under these conditions the correct mixture of ammonia and air is being drawn through the apparatus. The white fumes are due to excess of ammonia in the mixture.

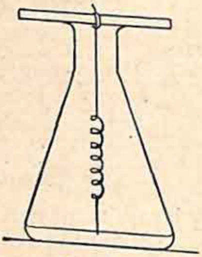


Fig. 31.

A simple variation of this experiment is to cover the bottom of a conical flask with 0·880 ammonia solution and suspend a spiral of platinum wire from a glass rod as shown in Fig. 31. The wire is now heated till it is red-hot and plunged as quickly

Important nitrates

Sodium nitrate is extracted on a large scale; its main uses have been given on p. 52.

Potassium nitrate (nitre or saltpetre) is also made in large quantities but not by the laboratory method. Sodium nitrate and potassium chloride, both obtained from minerals, are mixed in special proportions and dissolved in a little hot water. Under these conditions they react thus:

$$NaNO_3 + KCl \rightarrow NaCl + KNO_3.$$

Much sodium chloride (salt) comes out as a precipitate; it is filtered off while the solution is still hot. Then, on cooling, potassium nitrate crystallises out with just a little salt. By recrystallising the product, pure potassium nitrate is obtained.

Potassium nitrate is nearly 50 per cent. oxygen by weight, so that it makes substances burn easily; hence its use in making fireworks and **gunpowder**, a mixture of nitre, carbon and sulphur. Nitre is also used in preserving meat.

Silver nitrate is made extensively by a method similar to that used in Expt. 2, p. 57; it is used in the photographic industry.

Lead nitrate is made for the production of certain orange and yellow pigments, while other nitrates are needed to make coloured fireworks.

Some important uses of nitric acid

Nitric acid is needed for the production of practically all **explosives** and in making substances which are converted into **dyes.**

On p. 11 you learnt that the hydrocarbon benzene, C_6H_6, is obtained from coal-tar. When benzene is shaken with a mixture of concentrated nitric acid and concentrated sulphuric acid, the nitric acid reacts with the benzene, replacing one of the H atoms by a nitro-group, $-NO_2$. The product is **nitrobenzene,** $C_6H_5.NO_2$, a pale yellow, oily liquid, smelling of bitter almonds.

$$C_6H_6 + HNO_3 \rightarrow C_6H_5.NO_2 + H_2O.$$

Nitrobenzene can be made into **aniline,** $C_6H_5.NH_2$, which in its turn is the starting point for the production of various dyes. Nitrobenzene is thus an intermediate in the dyeing industry.

The following experiments are intended to demonstrate these changes in a simple manner :

Expt. A.—To illustrate the preparation of nitrobenzene.

Mix 5 c.c. concentrated nitric acid and 5 c.c. concentrated sulphuric acid in a boiling-tube. Add this mixture gradually to 2 c.c. benzene in a small flask ; shake well, allowing the mixture to become warm, but not so hot that the benzene boils ; if necessary cool the flask in a trough of water. Shake well for a few minutes when all the acid has been added. Pour the two liquids obtained into a boiling-tube half full of water. Pour off the top layer. Wash the oily liquid with water by decantation. Pass round the class to smell the nitrobenzene.

Expt. B.—To illustrate the preparation of aniline.

Put 5 grm. granulated tin into a boiling-tube and add 2 c.c. of nitrobenzene. Gradually add 10 c.c. concentrated hydrochloric acid to the mixture. Warm at first and shake well, but if the tube becomes too hot and the reaction vigorous, cool the tube. When the bulk of the tin has disappeared and the oily liquid is no longer apparent, heat the tube for a few minutes till the smell of nitrobenzene disappears.

Pour off the liquid into a small flask, cool a little, then add 30 per cent. caustic soda solution (if necessary add a little water to keep the contents of the flask fairly liquid) till the mixture is alkaline. Pass round the class to smell the ammoniacal odour of aniline.

Expt. C.—To illustrate the preparation of an aniline dye.

Dissolve a few drops of aniline in 5 c.c. dilute hydrochloric acid, cool under the tap, then add gradually a few drops of a solution of sodium nitrite, keeping the tube cold.

Dissolve a little β-naphthol in a few cubic centimetres caustic soda solution ; warm if necessary, then cool.

Now soak a piece of cotton (old handkerchief) in the second solution, squeeze it, then dip the cotton into the first solution.

The cotton is dyed red. If the two solutions are mixed, the dye separates as a red precipitate.

Another liquid obtained from coal-tar, which is closely related to benzene, is the hydrocarbon toluene, $C_6H_5.CH_3$. This liquid reacts under certain conditions with a mixture of concentrated nitric and sulphuric acids so that three nitro-groups replace three H atoms in the group $C_6H_5—$. The product, **trinitrotoluene, T.N.T.**, $CH_3.C_6H_2(NO_2)_3$, is a very important explosive, which is used for shell-filling and for depth charges.

Similarly, carbolic acid or phenol, $C_6H_5.OH$, another benzene derivative, is converted by the action of nitric acid into **picric acid**, $C_6H_2.(NO_2)_3.OH$. This yellow solid is the explosive lyddite; it is also a yellow dye.

Nitroglycerine is an extremely dangerous liquid explosive, which no student should attempt to make. This substance is not a nitro-compound as its popular name implies; it is a nitrate, glyceryl trinitrate, made by the action of concentrated nitric and sulphuric acids on glycerine:

$$C_3H_5(OH)_3+3HNO_3 \rightarrow C_3H_5(NO_3)_3+3H_2O.$$

Dynamite is a mixture of nitroglycerine and kieselguhr, a fine absorbent form of sand.

Cellulose (p. 15) reacts with concentrated nitric acid in a similar manner to glycerine, producing **cellulose nitrates** (wrongly termed nitrocelluloses), i.e. nitrate radicals ($NO_3—$) take the place of —OH groups in the cellulose. When the action of nitric acid on cellulose has been allowed to proceed as far as possible, the product, which is like the original cellulose in appearance, is called **gun-cotton.** This substance explodes violently if detonated even when it is wet.

Oddly enough by mixing gun-cotton, nitroglycerine, and a little vaseline with the solvent acetone, a fairly stable explosive, **cordite**, is obtained. The pasty mixture is squeezed through dies and the cords (hence the name) dried to remove acetone. Cordite is the "smokeless powder" used for propelling bullets and shells.

Nitrocelluloses which contain a lower proportion of nitrate radicals than gun-cotton, dissolve in certain solvents, e.g. acetone.

These solutions mixed with pigments and certain toughening substances, are widely used as paints and lacquers. Artificial leather consists of cotton impregnated with these substances.

Celluloid is a mixture of nitrocellulose and camphor ; the two substances after mixing are heated together under pressure. The resulting plastic substance is easily moulded at 75° C. ; it finds extensive use, e.g. for films, but it is dangerously inflammable.

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CHAPTER 7

PARASITES AND SAPROPHYTES

Bacteria

In Book I (p. 181) we learned that human disease was often caused by micro-organisms called bacteria. Bacteria are one of the commonest occurring forms of life. One gram of ordinary garden soil may contain 20–50 million living bacteria, and several times this number of dead ones. Few of these are disease producing types, most of them are fairly harmless and many are beneficial, as they promote the decay of dead plant and animal matter (p. 68).

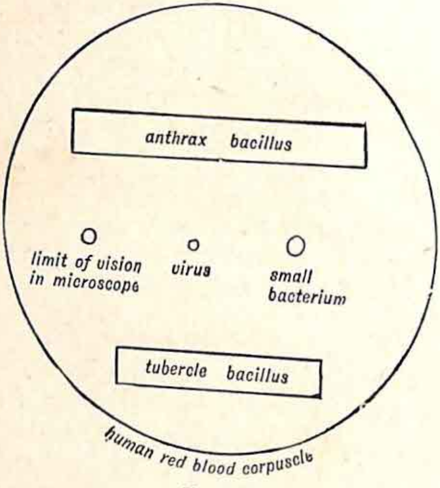
anthrax bacillus
limit of vision in microscope
virus
small bacterium
tubercle bacillus
human red blood corpuscle

FIG. 32.

Bacteria are some of the smallest of living organisms, and it frequently requires a very high magnification for a single bacterium to be visible at all. Fig. 32 shows the relative size of bacteria compared with other very small objects. Bacteria are known in various shapes (Fig. 33), e.g. spherical (cocci), rod-shaped (bacilli) and they may or may not have whip-like projections (flagella) by the lashings of which they can swim. Without flagella bacteria can only move where a current of fluid carries them.

Bacteria have no chlorophyll. They are sometimes regarded as simple forms of plants while many biologists regard them as apart from both animals and plants and classify them as a separate kingdom.

Bacterial cultures

In laboratories bacteria are often grown on the surface of various nutrient mixtures. These cultures enable the bacteria to be studied conveniently. If a dish containing a suitable mixture is exposed to the air or touched with an object it is usually possible to determine, from the resulting culture, what kinds of bacteria were present in the air or on the object. Each bacterium which falls on to the mixture grows, multiplies and gives rise to a large number, or *colony*, which can be more conveniently studied than the single organism.

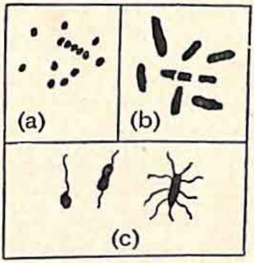

FIG. 33.
(*a*) cocci, (*b*) bacilli, (*c*) flagellate bacteria.

The life processes of bacteria

Bacteria need food in order to grow. As they have no chlorophyll they cannot build up food from carbon dioxide, water and salts in the manner of green plants. They need food in the form of compounds such as amino-acids and sugars. These can only be obtained from other living organisms or from their dead bodies. When one organism (e.g. a bacterium) draws its food from a living animal or plant without contributing anything useful in return, the two organisms are called **parasite** and **host** respectively. Disease-producing bacteria are parasites. Their hosts are human beings, other animals, or the plants which they infect. Other bacteria live on the dead remains of plants and animals which they dissolve by means of enzymes. Bacteria and other organisms which feed in this manner are called **saprophytes.** Saprophytic bacteria are often harmless or actively beneficial from man's point of view, and are much more numerous and important than the better known disease producing types.

In order to obtain energy some bacteria take in oxygen and use it to oxidise sugar. The oxygen diffuses in through the cell wall, and the waste products, water and carbon dioxide, diffuse out. Other bacteria do not need oxygen but obtain energy by breaking down complex substances with the aid of enzymes. Such changes are called **fermentation**, or, where objectionably smelling substances are produced, **putrefaction.**

In suitable conditions, such as moderate warmth and presence of an adequate food supply, bacteria grow to a certain limiting size (cf. Fig. 32) and then reproduce by division into two. When conditions are very favourable the time between successive divisions may be as little as 20 minutes. At this rate a single bacterium would give rise to over 1,000,000 bacteria in 7 hours. Needless to say, this does not occur, as overcrowding and food shortage would result. It means, however, that a few bacteria can quickly produce a large colony if food and warmth are present. Such conditions are present in warm milk. Hence milk is cooled quickly when first drawn. This also explains our difficulty in preventing souring (p. 66) in warm weather.

When conditions become unfavourable some kinds of bacteria can form themselves into **spores,** in which form they are very resistant to drying, disinfectants (p. 66) or heat. The spores are oval or spherical bodies which contain the vital contents of the bacterial cell within a tough envelope.

Spontaneous generation. Sterilisation

At one time the maggots in bad meat were thought to have been produced by the process of decay. We now know that it is the maggots which cause decay, rather than the reverse process, while the maggots arise from eggs laid there by a fly. Frogs were formerly believed to arise from the mud in ponds and streams. In many processes of decay, such as the fermentation of a soupy broth, no form of life was visible to the eye and the process was still more mysterious. Under the microscope the fermented liquid was seen to contain myriads of small creatures which were not apparently present in the soup at first.

Louis Pasteur, a French scientist, pointed out the real nature of fermentation. He placed a soupy liquid in several flasks with long, curved necks (Fig. 34), and boiled the liquid for some time. Afterwards he left the flasks to cool. No fermentation took place and the soups remained clear. Pasteur then broke off the upper parts of some of the flasks and left the liquid exposed. In a few days the liquids in these flasks became cloudy and swarmed with micro-organisms. Pasteur explained his results as follows. The boiling killed all living things in the soup, and consequently it could not decay. Air alone did not cause decay, since it could get in through the flask necks. Dust and floating particles were trapped by the condensed steam in the curved necks. When the flask was opened, particles floating in the air could get in. Some of these particles were floating micro-organisms. They settled on the soup, grew and multiplied in it, and caused it to decay.

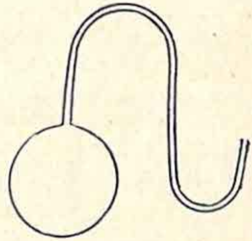

FIG. 34.

Pasteur's experiment showed that living things did not arise out of non-living matter, but had to be present before decay took place. The process of boiling is one of several methods which we now use to make objects or liquids free from living micro-organisms, i.e. **sterile.** We shall consider this process, **sterilisation,** in more detail in the next section.

The control of harmful bacteria

Disease bacteria produce harmful effects on man and his domestic animals and plants. Certain saprophytic bacteria also cause wastage of his assets, and he must therefore adopt methods of preventing or diminishing such effects.

Sterilisation destroys all forms of life in an object. A needle may be sterilised by making it red-hot, thus killing even spores. Ordinary boiling unless prolonged does not kill spores, and to make a liquid sterile it may be necessary to boil three times at intervals of a day or two, in order that spores shall resume their active form and then be killed. Empty milk bottles are sterilised by heating in steam, which is more effective than boiling water. Liquid milk is **pasteurised** by heating at about 145° F., which kills most active bacteria but not spores. After pasteurisation accession of more bacteria must be prevented if the milk is to keep sweet and free from harmful effects.

EXPT. 1.—*To examine the effects of pasteurisation and sterilisation.*

Place 50 c.c. of unpasteurised milk in three conical flasks and label them "A," "B" and "C." Loosely plug the neck of each flask with cotton-wool.

Keep A in a warm place. Stand B in a water bath which has been warmed to about 145° F.; keep it there for ½ hour and regulate the Bunsen to maintain the temperature at 145° F. Keep C in a boiling water bath for ½ hour. After the heating keep B and C in the same place as A, but repeat the heating of C on two successive days.

Without removing the cotton-wool note the time taken for clotting to occur in each flask (do not confuse with the separation of cream). When clotting has definitely occurred in a given flask remove the plug and confirm by smell that souring has occurred.

Antiseptics.—A century ago hospital operations resulted in death from gangrene in almost half the cases. Lord Lister saw that the cause was bacteria which spread from patient to patient and grew in the wounds. Lister sterilised his instruments, at first with carbolic acid and later by heating. This reduced the deaths following amputation from 43 to 15 per cent., a figure which has since diminished much further. Carbolic acid was called an antiseptic (anti=against; sepsis=putrefaction, flesh poisoning) since it prevented the poisoning which usually followed operations. More effective yet less corrosive antiseptics are now used.

Operations now take place in special rooms where precautions are taken to prevent bacteria from reaching the wound. These are known as **aseptic** (a=without) conditions. If we avoid dirt and cover food the sources of bacteria and their chances of breeding are diminished.

Disinfectants are chemicals used to destroy bacteria on objects as distinct from the human body. Carbolic acid can be used both as a disinfectant and an antiseptic, but may be employed in more concentrated solution in the former case.

Strong sunlight quickly kills bacteria and the bright but diffused light, such as is obtained in a light room, prevents their activities even when not actually destroying them.

Other methods of bacterial control

Sweetened condensed milk usually contains bacteria, but they cannot absorb water or feed owing to the high concentration of sugar.

It easily goes sour after dilution. Preservatives in food stop bacterial activity and more powerful ones, such as arsenic or naphthalene, prevent the decay of stuffed animals.

Sterile fruit juice which has neither been heated nor contains preservatives retains its full flavour. Bacteria have been removed by careful filtration into sterile receptacles. Cold storage stops bacterial activity, but the conditions must suit the particular food. Apples for instance must not be frozen since this kills the apple. The living apple resists decay better than the dead fruit. Desiccation or drying stops the activities of bacteria by depriving them of water.

Bacteria and disease

Bacteria harm our bodies by producing poisons (toxins) which damage the tissues, and by actual invasion by the germs.

Diphtheria germs settle in the mouth, throat or tonsils and produce a toxin which circulates and kills or paralyses cells in the brain and heart. Tetanus (lock-jaw) toxin spreads along the nerves to the brain and spinal cord, killing the nerve cells in its passage. In both these cases the actual germs remain in one region.

Anthrax is a disease of cattle which can spread to man. Spores of the bacillus (p. 62) enter through a scratch, multiply and spread, and may cause death from pressure of large masses of bacteria upon a vital organ.

The body protects itself by means of the white corpuscles which attack and devour germs, by forming antitoxins which neutralise the toxins and by producing other substances which weaken or kill the germs.

Useful bacteria

Ham and bacon are "cured" by the action of bacteria, salt and saltpetre on pork. The pink colour is due to a compound, nitroso-hæmoglobin, of the blood pigment and an oxide of nitrogen which is produced from the saltpetre. Like the compound of hæmoglobin and carbon monoxide, this substance is not easily converted to hæmoglobin and hence the pink colour is retained.

Milk is converted into cheese by the action of bacteria, but the flavour finally obtained often depends on a succession of micro-organisms, some of which are moulds (p. 71).

Linen is made from fibres of the stems of flax. After removing the seeds, the stalks are kept wet. Bacterial action known as "retting" occurs and loosens the fibres which can then be separated and spun into linen thread.

Probably the most important of all bacteria are those concerned with the circulation of carbon and nitrogen in nature. Without their aid the present population (animals and plants) of the world could not continue to exist. We shall give them a section to themselves.

The nitrogen cycle

The remains of plants and animals in the soil are attacked by saprophytic bacteria. Proteins are converted to ammonium salts. **Nitrifying bacteria** oxidise these to nitrates, in which form the nitrogen can be taken in by the root-hairs of plants and rebuilt into proteins and protoplasm. There is thus a circulation of nitrogen between living plants and dead plant and animal remains (Fig. 35).

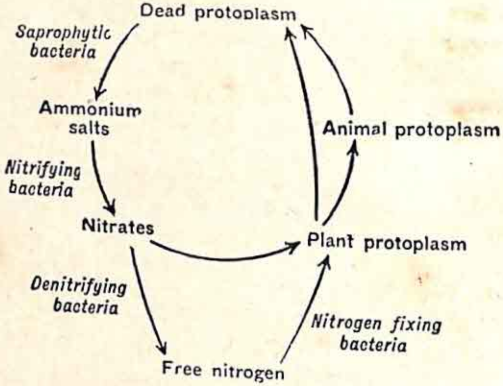
Dead protoplasm
Saprophytic bacteria
Ammonium salts
Nitrifying bacteria
Nitrates
Animal protoplasm
Plant protoplasm
Denitrifying bacteria
Nitrogen fixing bacteria
Free nitrogen

FIG. 35.

This simple cycle of events is disturbed by **denitrifying bacteria** which decompose nitrates and set free nitrogen which escapes into the air. Other nitrates are washed out of the soil into streams. Fortunately there are ways of making good these losses. **Nitrogen-fixing bacteria** live partly free in the soil, but largely in nodules on roots (Fig. 36) of legumes, plants with pods, such as peas, beans, lupins, and the agricultural crops, clover and lucerne. The bacteria in the root nodules convert nitrogen (from air spaces in the soil) to compounds which they supply to the plant, which in return supplies sugars to the bacteria. We have here an example of **symbiosis,** two organisms living together and each supplying something useful to the other.

Certain districts in Britain are deficient in nitrogen-fixing bacteria but special cultures of them are now produced and marketed.[1]

Lightning flashes cause the union of small amounts of oxygen and nitrogen and ultimately the formation of nitric acid. This is washed into the soil and forms nitrates.

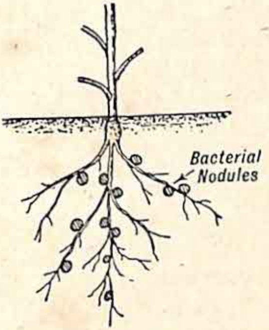
Bacterial Nodules

FIG. 36.

Man upsets the natural circulation of nitrogen by gathering crops and by wasteful methods of sewage disposal. On the other hand he produces artificial fertilisers and thus puts useful nitrogen back into circulation.

The carbon cycle (p. 25) also depends on the action of saprophytic bacteria for the essential processes of decay. The two cycles coincide in part, since, in living bodies, the nitrogen and carbon are present together in the same compounds, the proteins (Fig. 37).

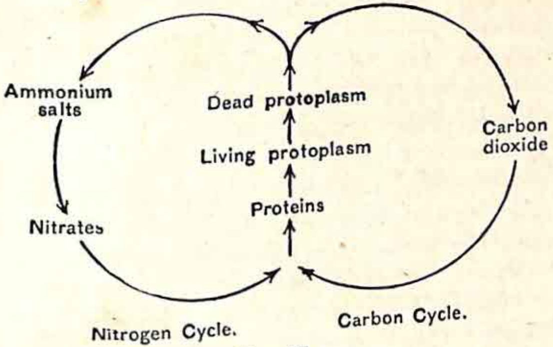
Ammonium salts
Dead protoplasm
Living protoplasm
Proteins
Nitrates
Carbon dioxide
Nitrogen Cycle.
Carbon Cycle.

FIG. 37.

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[1] Messrs. Allen and Hanbury supply single test-tubes of this culture with simple instructions for its use in the inoculation of lucerne seed.

Symbiosis

The "mutual benefit society" in the case of the nitrogen-fixing bacteria and the plant is not an isolated example of symbiosis. There is no digestive enzyme produced by the horse which can decompose cellulose, yet cellulose in the form of plant cell walls forms a large proportion of the horse's diet. Bacteria in the horse's intestine decompose the cellulose into material which the horse can utilise. In return the horse provides food, warmth and shelter for the bacteria.

A number of animals are known which are apparently green in colour, e.g. Hydra. The microscope reveals green plant cells living inside the animal. The animal provides home and shelter while the plants produce carbon compounds which the animal can use as food.

Viruses

Smallpox and measles, foot-and-mouth disease of cattle and certain plant diseases appear to be caused by organisms, yet no organism capable of causing them has been seen, even under the most powerful microscope. The name **virus** has been given to the causal organism in these cases. Virus diseases are not yet well understood, but some of them can be treated in a manner similar to bacterial diseases (cf. vaccination for smallpox).

Viruses pass through filters which retain bacteria, and can be cultivated (increased in quantity) on living tissues, but not, like bacteria, on gelatine. A number of viruses have been photographed by ultra-violet light. It has been suggested that they are forms of bacteria which have specialised on a completely parasitic life, dispensed with everything which is not needed for existence and reproduction, and become much reduced in size. They are certainly smaller than bacteria.

Yeast

Yeast is a simple form of plant life known as a mould. The single cells (Fig. 38) of which it consists produce enzymes which convert other forms of sugar into glucose (grape sugar), and an enzyme, zymase, which converts glucose into alcohol and carbon dioxide. This latter process also produces heat.

$$\underset{\text{glucose}}{C_6H_{12}O_6} \rightarrow 2CO_2 + \underset{\text{alcohol}}{2C_2H_6O} + \text{heat.}$$

This is a method of respiration. The plant uses the heat liberated to enable it to form fresh protoplasm. Since oxygen is not used, it is anærobic respiration. However, the alcohol produced kills the yeast eventually, and the process cannot continue indefinitely. When yeast is manufactured air is blown through the liquid and the sugar is oxidised to carbon dioxide and water. More heat is produced and the yeast grows very rapidly.

Yeast builds fresh protoplasm using dissolved nitrogen compounds and sugars for the purpose. Small bulges grow on the cells and then split off, a method of reproduction called budding. Sometimes the buds remain attached and short chains of cells result.

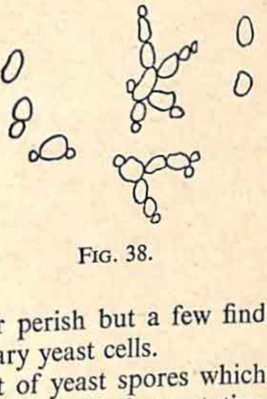

FIG. 38.

When yeast is starved the protoplasm of each cell divides into four. Each of the subdivisions covers itself with a cell wall forming a spore which escapes if the yeast dries up. The spores are blown about. A number perish but a few find suitable conditions and give rise to ordinary yeast cells.

The "bloom" of fruit consists in part of yeast spores which subsequently form yeast cells; these cause alcoholic fermentation when the fruit is crushed and the spores mix with the sugary juices. When the process is complete the liquid is separated from the yeast and fruit residues, and is known as wine or cider.

Yeast and yeast extracts are valuable sources of vitamin B, and are often sold as food.

Mucor, the pin-mould

EXPT. 2.—*To grow and examine pin mould.*

Wet a piece of bread and place it on a plate. Invert a dish over it to keep it moist and leave it for several days in a warm place. Examine it at intervals of a day or two, using a pocket lens. Note particularly the patches of grey mould, Mucor. Patches of other colours are due to other moulds or to bacteria. When there are well developed patches of Mucor, carefully examine its upper surface and also cut a vertical slice through the bread at the spot and examine the cut surfaces. Describe your observations.

Mucor, the grey mould which develops on jam or damp bread, is spread by air-borne spores. When one settles on damp bread it sprouts and sends a hollow branching tube, or **hypha,** down

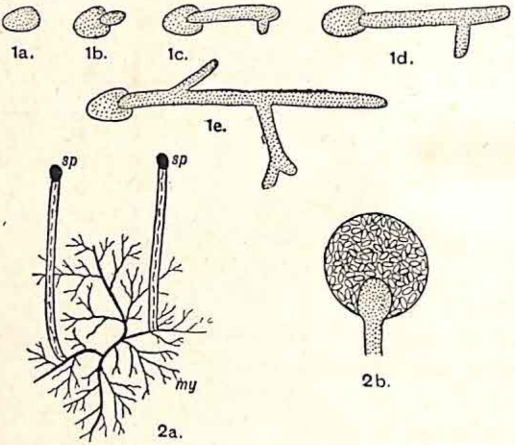

FIG. 39.

Mucor. 1a, b, c, d, e : development and branching of hyphæ from a spore. 2a, *my*, mycelium; *sp*, spore case. 2b, spores inside spore case.

into the bread. The branching hyphæ form a **mycelium** or network of thread-like tubes (Fig. 39).

Mucor is saprophytic. The hyphæ secrete enzymes which dissolve some of the bread outside the tube. The nutrient solution is then reabsorbed and used as food.

Mucor reproduces by spores. Some of the hyphæ grow away from the surface, and dark-coloured spore cases develop, giving the appearance of a number of black-headed pins, which is responsible for the name pin-mould. Spores develop inside the case and escape when it bursts. Those of them which later fall on suitable material, such as jam, or another piece of damp bread, sprout, send out branching hyphæ and form fresh mycelia.

Mucor can also reproduce by conjugation between the tips of hyphæ from two slightly differing types of the mould. A zygospore is formed which, after a period of rest, produces a spore case. The spores, when released from this, can give rise to fresh Mucor plants.

Fungi

Non-flowering plants which have no chlorophyll, e.g. yeast and Mucor, are called **fungi.** Another fungus is the bluish-green mould on oranges, while larger examples are the mushrooms, toadstools and puffballs.

Yeast is rather an exceptional type of fungus, but Mucor illustrates some of the more general characteristics of this type of plants. In the absence of chlorophyll a fungus cannot build up carbohydrates from water and carbon dioxide. Consequently it must be supplied with complex food substances. It usually obtains these by a mycelium of hyphæ which secrete enzymes and reabsorb the digested food. A fungus usually reproduces by spore formation, though, as we have seen, there are also other methods.

Owing to their method of nutrition fungi must feed either on living organisms, in which case they are parasites, or on dead material, in which case they are saprophytes. There are in addition a number of fungi which live in partnerships with green plants, another example of symbiosis.

Damage by fungi

Most plant diseases are caused by fungi, and cures are seldom possible. Plants may be protected by spraying, and by careful handling, since attack often starts on a damaged part. Once the plant is attacked the affected parts may be cut off and burnt, or it may be necessary to burn the whole plant. Some fungi damage plants by producing toxins which enter the tissues of the host. In such cases it is often possible to produce varieties which are immune to a particular disease. Dealers in " seed " potatoes classify their products as immune or otherwise to wart disease, a fungus pest which produces wart-like excrescences on the stems and tubers.

Potato blight, another fungus, almost destroyed the Irish potato crop about a century ago and produced widespread famine in which about a quarter of a million people died. Yellow rust, so called from its appearance on infected leaves, is the chief wheat pest in this country. It destroys leaves, thus preventing photosynthesis and reducing the yield of grain. It persists throughout the winter on self-sown plants (produced from seeds which have fallen out of the ears) and reinfects subsequent crops.[1] Important varieties of wheat which are immune to this have been produced (p. 225).

Ringworm, trench feet and moulds on salmon are fungus diseases, but on the whole fungi tend to attack plants and insects, whose stomata and breathing tubes respectively give easy access to the less protected inner parts.

Dry rot of wood is caused by a saprophytic fungus, the ravages of which were formerly the chief cause of the annual renewal of 500,000,000 posts on the United States' railways. The use of wood preservatives and of concrete posts have reduced much of this needless waste.

Useful fungi

Yeast is used in the beer, wine and cider industries, and in bread-making where the bubbles of carbon dioxide cause the bread to "rise." Other kinds of yeasts produce different reactions and it is necessary in yeast production to isolate carefully the kind which is required.

Moulds are responsible for the ripening and flavour of certain types of cheese, e.g. Gorgonzola. Lichens are associations (symbiotic) of a fungus and another simple type of plant. Litmus, and many of the colours used in dyeing tweeds, are obtained from lichens. Manna, on which the children of Israel fed in the wilderness, consists of lichens. Wind-borne "rains" of manna still occur.

Mushrooms and many other fungi including truffles and toadstools are used as food, particularly on the continent of Europe.

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[1] Other rusts with more complicated life-histories are also known.

Near Bath an annual crop of 250,000 lb. of mushrooms is produced in underground tunnels, while a similar industry round Paris produces 2½ tons per day. These industries propagate the fungi by means of "spawn" which consists chiefly of the mycelium. Cultivation from spores has not yet been commercially successful.

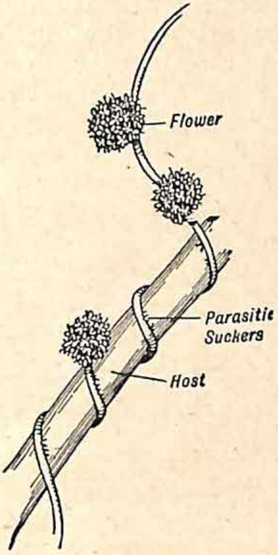

FIG. 40.

Dodder

Some flowering plants are parasitic. Dodder (Fig. 40), is a flowering plant, varieties of which are parasitic on nettles, gorse, hops and clover. Its seed contains very little reserve food. On germination the first part to emerge grips the soil, but later reddish or yellow thread-like stems curl round the leaves and stems of the host, here and there sending in suckers (Fig. 41) to the host's wood vessels. If no host is found the seedling dies. The connection with the soil withers soon after the host is found, and thereafter dodder draws all supplies from its victim.

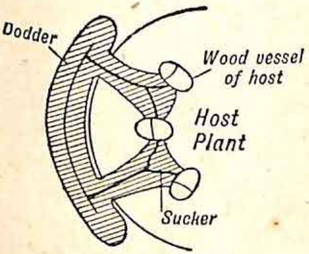

FIG. 41.

Dodder bears no foliage leaves but late in the season forms groups of small flowers which can be either wind- or self-pollinated, and give rise to seeds.

Mistletoe

Mistletoe is an evergreen which contains chlorophyll. Its white berries contain seeds and a sticky substance. When birds eat the seeds, some get stuck to their beaks and are wiped off on branches of trees. Seeds spread in this way germinate and produce suckers which penetrate to the wood vessels of the tree. Next year leaves are formed and the plant behaves as a partial parasite, drawing water and salts from its host but carrying out photosynthesis. Branches of the sucker spread along crevices of the bark, put down fresh suckers and give rise to fresh bushes. The chief host is the apple, but oaks and other trees are seen bearing the well-known bushes.

CHAPTER 8

FORCE. CENTRE OF GRAVITY. MACHINES

What is a force?

Although we all understand in a general way what is meant by the word "force," careful consideration of *what a force can do* is necessary before the scientific meaning of this word can be defined. Every object at rest *tends* to remain at rest, or, if in motion, it *tends* to continue its progress without alteration of speed or direction. Because of this tendency to remain as it is, we say that the object possesses **inertia**, and its condition of rest or movement can only be altered by overcoming its inertia. *To do this we must apply a force.*

Consider the operation of a garden roller. The force applied, by muscular or mechanical means, may

(*a*) set the roller in motion and quicken its speed ;
(*b*) slow down its motion and stop it ;
(*c*) alter its direction of motion.

In each instance the action of the force changes either the speed or the direction of movement of the roller.

But we also recognise that a force must be employed to keep the roller moving at a steady rate, or, if the roller is heavy, the application of a small force may not start it from rest. These seem to contradict the principle of inertia. In practical considerations of movement on earth there are always *resistances to motion* and the chief of these is friction. In starting and accelerating the roller, part of the force you apply is used to neutralise these resistances, and the remainder then starts and accelerates the roller. If, when the roller is in motion, the propulsive force is removed, the resistive forces reduce the speed of the roller and bring it to rest. The inertia of the roller tends to maintain the motion ; the resistive forces change this motion.

To keep the roller moving steadily we must apply sufficient force to neutralise the resistance, but no extra force is needed to maintain the motion.

We conclude, therefore, that the action of a force is to overcome the inertia of an object, either by changing its speed, or its direction, or both. The precise conceptions of inertia and of force were first clearly stated by the great English mathematician and scientist Sir Isaac Newton (1642–1727).

How forces are measured

Consider a lump of metal suspended by a string. Gravity (Book II, p. 219) tries to pull the lump towards the centre of the earth. Thus gravity produces a force. The strength of this force depends upon the object on which it is acting. Thus the force on a 2-lb. weight is twice as great as that on a 1-lb. weight. We shall call the force of gravity acting on a 1-lb. weight *a force of* 1 *lb*. The advantage of this method of stating strengths of forces is that we can easily arrange measureable forces in our experiments.

We learned in Book I (p. 8) that a spring-balance can be used to find the weight of an object. The reading on the scale indicates the weight suspended on the hook and therefore indicates the *force* on the hook. A spring-balance can therefore also be used to measure forces.

The turning power of a force

If an object is provided with a fulcrum about which it can turn, the application of a force at any other point of it will cause it to turn. We investigate the *turning-power* of a force as follows:

Expt. A.—To investigate the turning power of a force.

The apparatus (Fig. 42*a*) consists of a wooden bar XY, about 20 in. long, provided with a fulcrum at its centre. The latter may consist of a thin peg inserted into a hole in the bar, but a specially made bar with a knife-edge support (Fig. 42*b*) is preferable.[1] The bar is graduated in inches and tenths (or cm.

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[1] If the bar does not balance, a paper rider should be appropriately placed on it to make it balance.

and mm.) with the zero of the scale at the fulcrum. Sets of $\frac{1}{10}$ lb. (or 50 grm.) disc weights A and B are suspended from the bar by cotton loops.

A and B are first made equal and their positions adjusted to keep the bar horizontal. The weights and their respective distances from the fulcrum are recorded. A is not altered in size or position, but B is now altered in weight and its position adjusted for the bar again to balance. The new weight and its distance from the fulcrum are recorded. A series of values for the size and position of B is entered in a table.

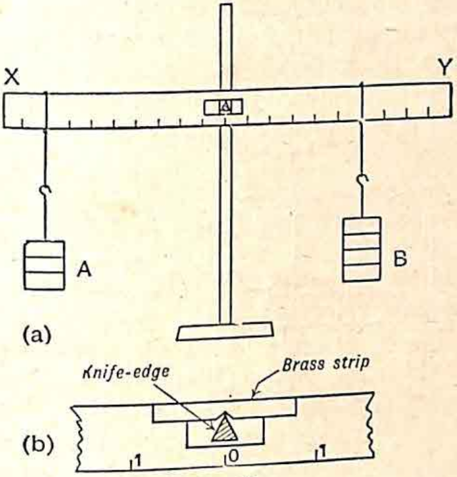

FIG. 42.

Force B	Distance from fulcrum	Force × distance
0·4 lb.	6·0 in.	2·4

As A is unchanged, in size and position, throughout the experiment, its turning-power on the bar is constant. *When the bar is balanced, the turning-power of B, acting in the opposite sense, equals that of A.* Hence, for each set of readings, the turning-stated by the great English mathematician and scientist Sir Isaac Newton (1642–1727).

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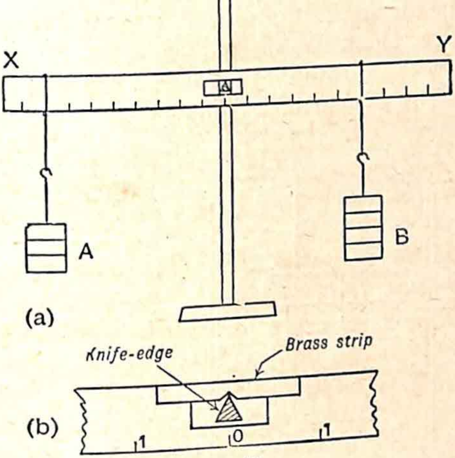

FIG. 42.

distances from the fulcrum are recorded. A is not altered in size or position, but B is now altered in weight and its position adjusted for the bar again to balance. The new weight and its distance from the fulcrum are recorded. A series of values for the size and position of B is entered in a table.

Force B	Distance from fulcrum	Force×distance
0·4 lb.	6·0 in.	2·4

As A is unchanged, in size and position, throughout the experiment, its turning-power on the bar is constant. *When the bar is balanced, the turning-power of B, acting in the opposite sense, equals that of A.* Hence, for each set of readings, the turning-power of B must be constant. Now multiply together each value of B and its corresponding distance from the fulcrum, and enter the products in the third column of the table. We find that, allowing for experimental error, *the products are constant.* Thus we conclude that **the turning-power of a force can be measured by the product of its strength and its distance from the fulcrum.**[1] The turning-power of a force is also called its **moment** ; it is described as clockwise or anti-clockwise in accordance with the direction of the turning it may cause.

The moment of A can be calculated and compared with that of B. They are found to be equal. Now assemble the apparatus as in Fig. 43, and test whether the moments of A and B are equal for this arrangement. Test also when B is acting nearer to the fulcrum than A. We conclude that the bar balances when the clockwise moment is equal to the anti-clockwise moment. This fact, first worked out by Archimedes (Book I, p. 17) is called **the principle of the lever.**

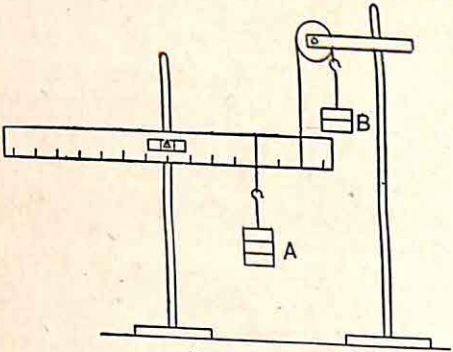

FIG. 43.

The principle of the lever and weighing

The balance or " pair of scales " has been in use as an instrument for weighing for many centuries. Inscriptions on tombs show that it was known to the ancient Egyptians. Although the balancing of the beam is governed by the equality of the moments of the weights in the scale-pans, a knowledge of the law of the lever is unnecessary for the use of the instrument. As the arms of the beam are equal, the weights in the scale-pans must be equal when the beam balances. It is possible, however, by utilising the principle of the lever, to weigh an object if only one standard weight is available.

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[1] If the direction of the force is not perpendicular to the bar, the *perpendicular distance* between the line of action of the force and the fulcrum must be taken.

EXPT. 1.—*To use the principle of the lever to determine the weight of an object.*

Apparatus : Graduated lever with central fulcrum and support, known weight (e.g. ½ lb. or 200 grm.), metal lump, cotton loops.

Assemble the lever and, if necessary, make it rest horizontally by adjusting a paper rider on one arm. Suspend the metal lump A by a cotton loop from the left-hand arm and restore the balance by suspending the known weight B from the appropriate point on the right-hand arm. Record the distances from the fulcrum of the loops supporting A and B. Alter the position of A and readjust the position of B for a balance, and again record the distances. Three or four sets of readings are taken and entered in a table :

B	Distance of B from fulcrum	Moment	Distance of A from fulcrum	A
0·5 lb.	8·3 in.	4·15	6·5 in.	0·64 lb.

Calculate the moment of the right-hand force B for each set of readings and, noting that the value also gives the moment of the left-hand force A, work out the value of A. Finally evaluate an average value for A.

The Roman Steelyard (Fig. 44) utilises the principle of the above experiments, but is arranged so that the required weight

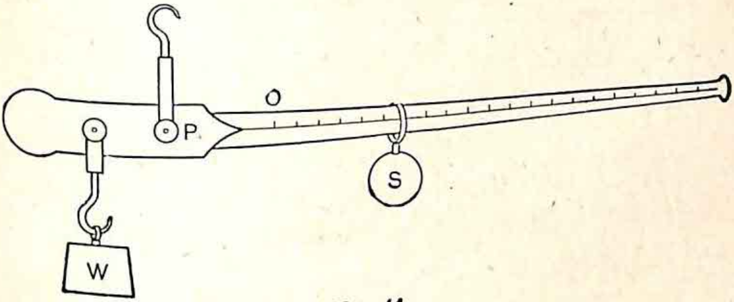


FIG. 44.

may be read off without calculation. It consists of a steel bar pivoted at P. *The shorter arm* (*with its hook*), *even when unloaded, is heavier than the longer arm*, so that a constant sliding weight S is required to maintain the balance. S must be placed at O when no load hangs from the shorter arm. The object W to be weighed is suspended by the hook on the shorter arm and S moved to the right to restore the balance. A scale of weights is marked on the longer arm and the weight of W is read off at the position of S. The steelyard was used by the Romans for weighing corn. We use it nowadays for weighing heavy and bulky objects.

The replacement of several parallel forces by one force

Consider an object which is acted upon by a number of parallel forces, e.g. a scout's trek-cart being towed by several scouts each pulling, in the same direction, on separate ropes. We enquire how strong a single force must be, and at what point it must act, to have the same effect as the parallel forces.

Expt. B.—To investigate the replacement of a system of parallel forces by a single force.

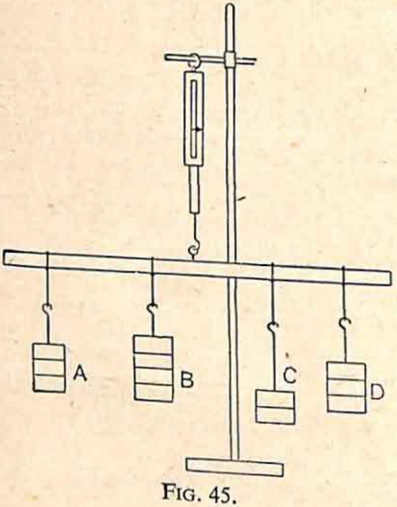


FIG. 45.

A wooden bar or lever, provided with a hook at the centre of its upper edge, is supported horizontally from a spring-balance. Several sets of disc weights A, B, C, D, are suspended by cotton loops from the bar and their positions adjusted so that the bar balances (Fig. 45). The values of the weights and the reading of the spring-balance are recorded.

The weights A, B, C, D, form a system of parallel forces. If a single force is to have the same effect on the bar it must (*a*) keep the bar horizontal, (*b*) give the same reading of the spring-balance. Condition (*a*) is satisfied if the single force is suspended immediately below the spring-balance, i.e. *at the point about which the bar is made to balance.* Why? We therefore remove the weights A, B, C, D and suspend a single set of disc weights immediately below the spring-balance. The weight is now adjusted until the spring-balance gives the same reading as previously. We find that the single weight must equal the sum of the weights A, B, C, D.

The system of parallel forces can be exactly replaced by a single force, equal in strength to the sum of the forces, and acting at the balancing point of the forces. The single force is called the **resultant** of the forces.

Centre of gravity

We now consider more carefully the force of gravity acting on an object. *Every particle* of the object experiences a downward pull, i.e. every particle has weight. This multitude of forces forms a system of parallel forces and their effect on the object can be exactly represented by a single force, the resultant, acting at the balancing point of the forces. This single force W (Fig. 46) is the sum of the separate forces and is therefore equal to the *weight* of the body. It acts at a definite point G. **The object behaves as if its weight were concentrated at one point. This point is called the centre of gravity of the object.**

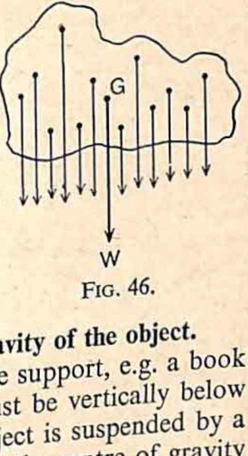


FIG. 46.

If the object is to be balanced on a single support, e.g. a book balanced on the finger-tip, the support must be vertically below the centre of gravity. Similarly, if the object is suspended by a string, or pivoted, it will come to rest with the centre of gravity vertically below the support.

To find the position of the centre of gravity

The centres of gravity of regular geometrical shapes (e.g. circle, rectangle) cut from thin, uniform material are at their geometrical centres. Thus the centre of gravity of a rectangular sheet of cardboard is at the intersection of the diagonals. In the case of other geometrical shapes (e.g. semicircle) and irregular shapes an experimental method may conveniently be used.

EXPT. 2.—*To determine the centre of gravity of a semicircular sheet of cardboard.*

Apparatus : Semicircular sheet of cardboard (diam. 7–8 in.), large pin, plumb-line, drawing-board, stand and clamp, cm. scale.

Clamp the drawing-board vertically and suspend the cardboard in front of it by means of the pin through a hole P near one corner (Fig. 47). See that the cardboard swings freely and then attach the plumb-line to the pin so as to hang just in front of the cardboard. Mark a point Q immediately behind the lower part of the plumb-line. Pierce another hole R and repeat the operation, so marking another point S. The required centre of gravity is vertically below P in the first case and vertically below R in the second case. Make the necessary construction to fix the position of the centre of gravity and check the point by means of a suspension from another hole T. Check also by trying to balance the cardboard on the pin's head placed at this point.

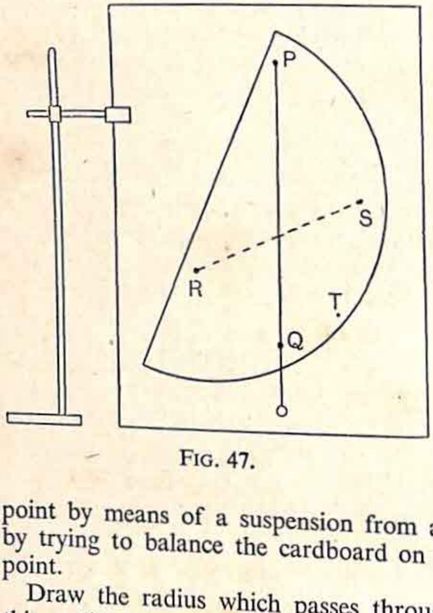


FIG. 47.

Draw the radius which passes through the centre of gravity. Is this radius a special one? Make the necessary measurements to calculate what fraction of the way along this radius the centre of gravity lies. Could this method be used for (*a*) a solid, such as a block of wood, (*b*) a circular cardboard ring?

When will an object topple over?

EXPT. 3.—Draw the diagonals on the face of a rectangular piece of cardboard to locate the centre of gravity. Place the cardboard flat on the bench and gradually push it over the edge. When it begins to overbalance, note the position of the centre of gravity with respect to the edge of the bench.

The experiment shows that **as soon as the object is moved so that the vertical line through the centre of gravity passes outside the surface of the support it will topple.** Fig. 48 (*a*) shows the cardboard in a safe position with its centre of gravity G above the bench. Fig. 48 (*b*) shows the cardboard projecting so far over the edge of the bench that the vertical line through G passes outside the bench. The weight of the cardboard, acting at G, has a moment about the edge of the bench and so causes turning of the cardboard about this edge.

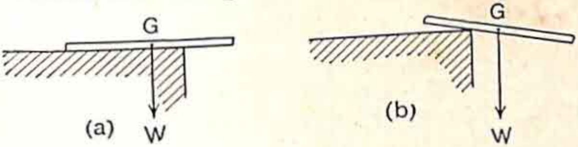


FIG. 48.

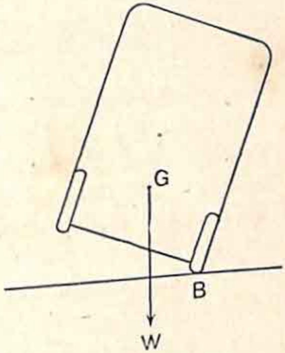


FIG. 49.

It is necessary that objects which must be free from toppling if slightly tilted should be so designed that the weight, acting at the centre of gravity, always tends to restore the object to its normal position. Thus the centre of gravity of a bus is arranged to be as low as possible, so that if the bus is tilted, even through a much larger angle than is likely to be experienced (Fig. 49), the weight has a moment about the edge B of the lower wheels, tending to restore the bus to an upright position.

If an object is supported so that its centre of gravity lies directly *below* the support, it is safe from toppling. Several amusing toys are based on this, and Fig. 50 shows how you can make one from an empty match-box and a penknife.

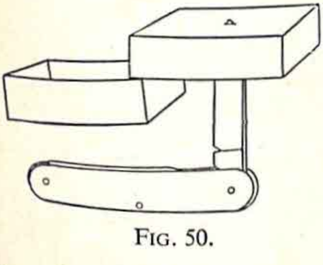


FIG. 50.

Simple machines

Man frequently uses some tool or appliance to enable him to perform his tasks more easily. A mason uses rope and pulleys to hoist stone blocks, a countryman uses a winch to raise a bucket of water from a well, a boy uses a tyre-lever to remove a bicycle tyre. These appliances are examples of **simple machines.** Many such machines have been known since early times. Wheels and levers are of great antiquity. The stone blocks used in the building of the pyramids were probably hauled up specially made inclines of earth. Archimedes first understood the main *principles* underlying simple machines and devised many fearsome machines to defend his city against the Romans.

What will a simple machine do?

In all simple machines a force, called the **effort,** must be applied. The action of the machine is to make available another force (usually greater) to raise a load or **overcome a resistance.** We define the **mechanical advantage** of the machine thus :

$$\textbf{Mechanical advantage} = \frac{\textbf{resistance overcome}}{\textbf{effort exerted}}.$$

If this is greater than unity, the machine makes available a force greater than the effort.

The distance through which the effort moves is not necessarily equal to the distance through which the resistance is overcome, and therefore the effort may move more quickly (or more slowly) than the resistance overcome. We define the **velocity ratio** of the machine thus :

$$\textbf{Velocity ratio} = \frac{\textbf{distance through which effort moves}}{\textbf{distance through which resistance is overcome}}.$$

If this is greater than unity, the resistance is moved a distance less than the effort and therefore more slowly.

Levers

The lever is one of the simplest machines and often an important part of more complicated machines. The three kinds (or orders) of levers have already been described (Book I, p. 124); these must now be examined more closely to determine how useful, or otherwise, the levers of each order may be when used as machines.

First order. Fulcrum between effort and resistance (Fig. 51)

Referring to Fig. 51 *a*, it is evident that if the bar balances,

$$\text{resistance} \times \text{arm CF} = \text{effort} \times \text{arm FD}.$$

A very slight increase in the effort now moves the resistance. If this lever is to be employed usefully, i.e. so that the mechanical advantage exceeds unity, the arm FD must be greater than the arm CF. Examples of this order are the handle of a lift-pump the 3-speed gear lever on a bicycle, the lever of a "self-filling" fountain pen (Fig. 51 *b, d*) and a claw hammer used

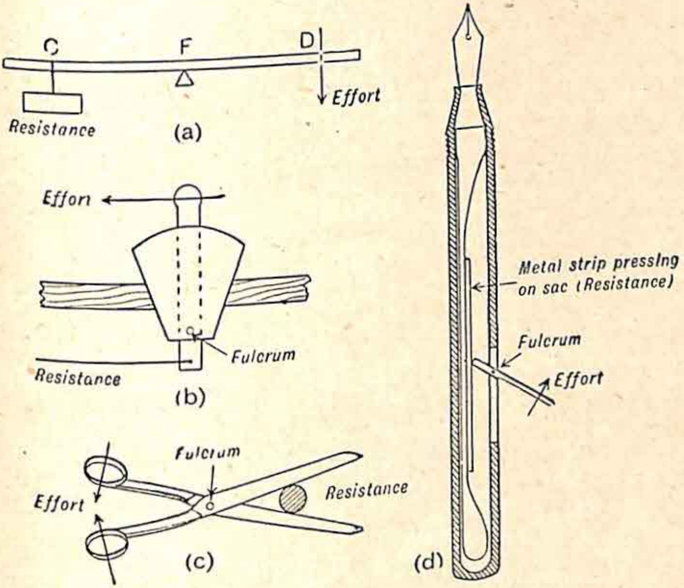

C
F
D
Effort
Resistance
(a)
Effort
Fulcrum
Resistance
(b)
Fulcrum
Effort
Resistance
(c)
Metal strip pressing on sac (Resistance)
Fulcrum
Effort
(d)

FIG. 51.

for extracting nails. A pair of scissors or garden shears (Fig. 51*c*) is an example of a double lever of the first order.

Second order. Resistance between fulcrum and effort (Fig. 52)

For convenience the fulcrum is usually placed at the end of the bar. In this order, since the arm FD always exceeds CF, the mechanical advantage is *always* greater than unity, and levers of this order may always be employed advantageously for raising heavy loads through short distances. Examples of this order are a tin-opener (Fig. 52 *b*), the brace and bit, and a pair of bellows. A pair of nut-crackers (Fig. 52 *c*) is a double lever of this order.

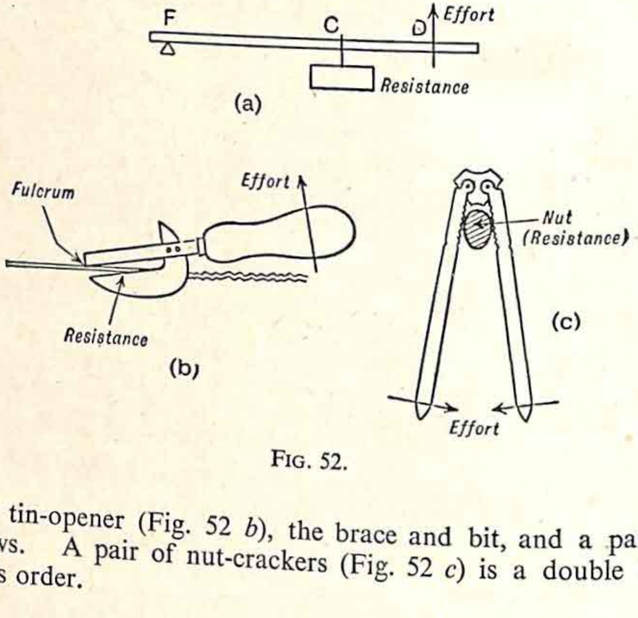


FIG. 52.

Third order. Effort between fulcrum and resistance (Fig. 53)

Since the conditions of this order reverse those of the second order, the arm FD must always be shorter than CF; thus the mechanical advantage is *always* less than unity, and levers of this order require an effort greater than the resistance to be overcome. Examples of this order are the treadle of a lathe, the safety-valve of a steam-engine (Fig. 53 *b*), and, as a double lever, a pair of coal-tongs (Fig. 53 *c*).

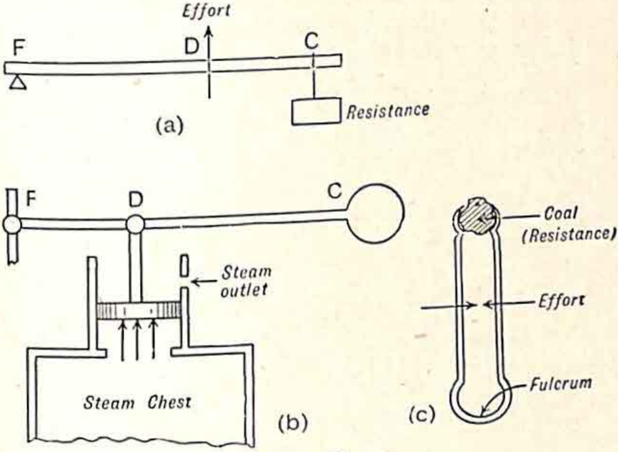


FIG. 53.

The human skeleton provides examples of all three orders of levers (Book I, p. 123).

Wheels in machines

If circumstances demand that the effort or the resistance must be moved through a large distance, a machine involving a *rotating* device must be used.

Fig. 54 *a* shows a **simple winch.** Its action is really dependent upon the principle of the lever, but both effort and load can move through large distances. Fig. 54 *b* shows that if the handle is on the opposite side to the rope (e.g. at A) it forms, with the drum, a lever of the first order, and when it is on the same side as the rope (e.g. at B) it forms a lever of the second order. In both positions the mechanical advantage is greater than unity. By considering the distance moved by the effort and by the load in one turn, the velocity ratio is seen also to be greater than unity.

Cog-wheels.—If a small cog-wheel drives a large cog-wheel, the mechanical advantage exceeds unity, but the larger wheel turns more slowly. A large cog-wheel drives a small one more quickly but with loss of force. The velocity ratio is that of the number of teeth on the driven wheel to the number of teeth on the driving wheel. The same result is achieved if the cog-wheels, instead of being in contact, are linked by a chain, or if pulleys are linked by a belt (friction causing the belt to turn with the pulleys).

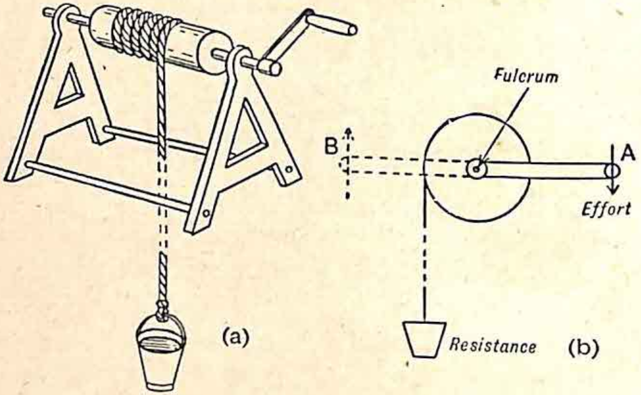


FIG. 54.

The driving mechanism of a **bicycle** utilises both principles described in this section. *Draw a simple diagram and state the action of each part.*

Pulleys

Expt. C.—To study the mechanical advantage of a single pulley which is (a) fixed, (b) movable.

(*a*) The apparatus is assembled as in Fig. 55 *a*, using stout cotton and $\frac{1}{10}$ lb. (and sub-decimal) disc weights. The effort required just to lift a given load after the effort has been given an artificial start [1] is found. This is repeated for different loads. We conclude that there is *no gain of force* (actually a slight loss) and *no loss of speed.* The use of the pulley is *to change the direction of pull.*

(*b*) The apparatus is assembled as in Fig. 55 *b*. The fixed pulley is used to enable the effort to pull downwards ; it does not appreciably alter the mechanical advantage. The effort required just to lift a given load is found and the mechanical advantage evaluated. By measuring the vertical movements of the load and the effort, the velocity ratio is deduced. The procedure is repeated for different loads. We find that the action of a movable pulley is to give a *mechanical advantage of nearly* 2 *and a velocity ratio of* 2.

---

[1] The effort required to *start* the load slightly exceeds that to maintain motion and produces acceleration.

A knowledge of the action of single pulleys enables us to understand the action of more elaborate systems. The **block and tackle** will be studied in illustration.

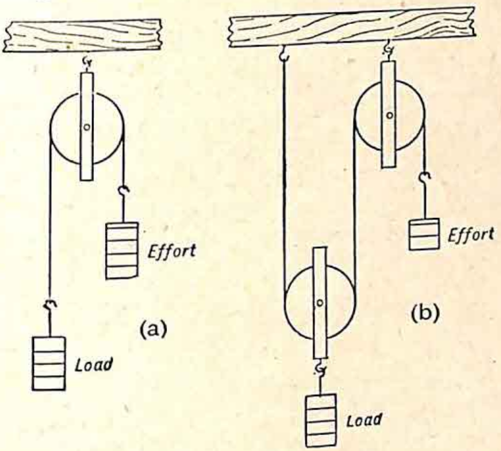


FIG. 55.

Expt. D.—To study the mechanical properties of a block and tackle.

The apparatus (Fig. 56 *a*) consists of a fixed "block" carrying two pulleys and a lower movable "block" with two pulleys. (In practice the pulleys are mounted freely, side by side, in the block, Fig. 56 *b*.) The same cord passes round all the pulleys, one end being fastened to the fixed block and the other passed over an additional single fixed pulley for the application of the effort. The appropriate measurements are made to determine the mechanical advantage and the velocity ratio for different loads, and the results entered in a table :

Load	Effort	Mechanical advantage	Distance moved by effort	Distance moved by load	Velocity ratio
1·4 lb.	0·44 lb.	3·2	3·0 in.	0·75 in.	4

Does the mechanical advantage change with load ? How can you account for this ?

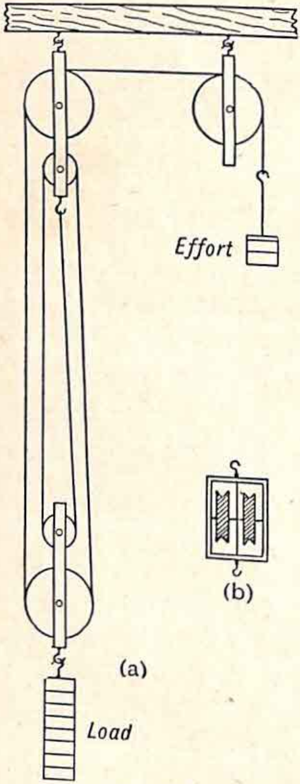


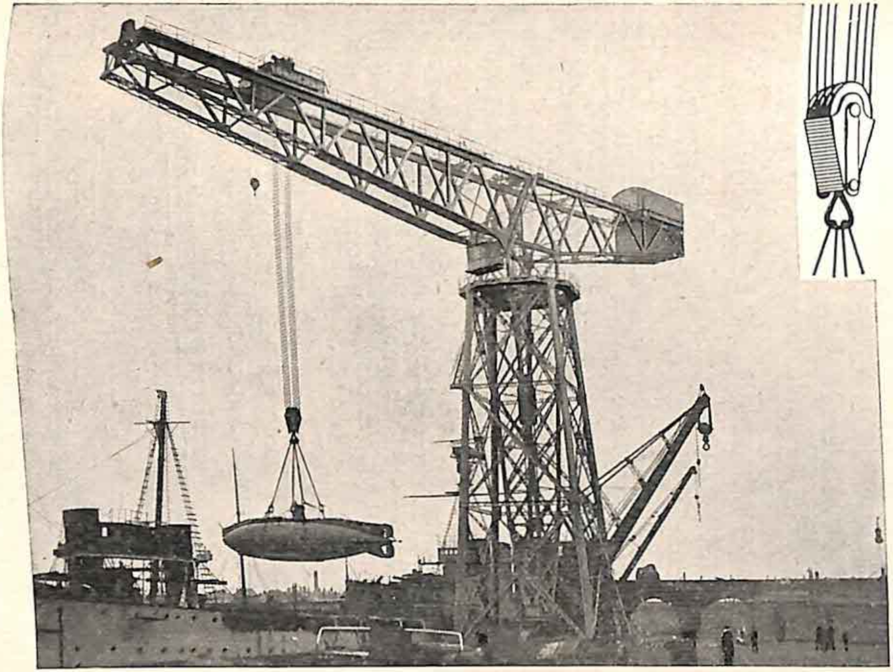
FIG. 56.

In practice the movable block may contain more than two pulleys and the fixed block an equal number of pulleys. The fixed pulleys serve to alter the direction of pull, with a slight loss of usefully applied force. *Each* movable pulley gives a velocity ratio of 2 and a mechanical advantage of nearly 2.

Work and efficiency

Our study of simple machines shows us that a large mechanical advantage is always accompanied by a large velocity ratio. Thus if a small effort is to be used to overcome a large resistance, the effort must move, in the same time, through a greater distance than the resistance. The figures obtained in our experiments with pulleys show that the mechanical advantage is roughly equal to the velocity ratio. We now investigate this more fully.

When a force overcomes a resistance and moves the point at which it is applied, **work** is said to be done. Thus work is done in dragging a box along the ground, in rowing



[By courtesy of Messrs. Vickers-Armstrongs, Ltd

CRANE LIFTING 150-TON SUBMARINE.
(The inset shows the lower pulley block.)

a boat, in carrying a parcel upstairs, in winding a clock. If the force is unable to move the point where it is applied, no work, scientifically, is done.

In hoisting a load by a rope and single fixed pulley to the top of a building, it is evident that the work which has to be done depends upon (*a*) the weight to be overcome, i.e. the *force* required, (*b*) the *height* through which the load is raised. The quantity of work done is measured by multiplying together these two factors .

$$\textbf{Work} = \textbf{Force} \times \textbf{Distance.}$$

If a force of 1 lb. operates through a distance of 1 ft., 1 foot-pound (ft.-lb.) of work is done. If you carry a 10-lb. parcel through a *vertical* height of 20 ft., you do 200 (i.e. 10×20) ft.-lb. of work (plus the work done in raising your body 20 ft.).

In the record given (p. 92), an effort of 0·44 lb. raised a load of 1·4 lb. Not all of this effort is used in raising the load, for the lower block has to be raised as much as the load and the axles of the pulleys are not frictionless. Now when the load is raised 1 ft., the effort moves through 4 ft. Thus the work done by the exertion of the effort, called *the work done on the machine*, is $0{\cdot}44 \times 4 = 1{\cdot}76$ ft.-lb., but the work performed solely in raising the load, called the *useful work done by the machine*, is $1{\cdot}4 \times 1 = 1{\cdot}4$ ft.-lb. The fraction $\frac{1{\cdot}4}{1{\cdot}76}$ shows how efficiently the work done by the effort has been used by the machine in raising the load, and is called the **efficiency** of the machine.

$$\textbf{Efficiency} = \frac{\textbf{useful work done by machine}}{\textbf{work done on machine}}.$$

It is usually expressed as a percentage, e.g. $\frac{1{\cdot}4}{1{\cdot}76} = 80$ per cent. Now evaluate the efficiency for different loads raised by the block and tackle in Expt. D.

The screw

A screw is a cylindrical or tapering rod with a ridge or *thread* arranged spirally round its curved surface. The distance between corresponding points of the thread (e.g. A, B, Fig. 57) is constant and is called the *pitch*. If the screw is turned into a fixed socket bearing grooves to correspond to the thread, it will advance by its pitch for each turn. Alternatively, if the screw is fixed, a free socket may be caused to move. The moving part can carry a load or overcome a resistance. The effort must be applied to cause the screw to turn, e.g. by acting on an arm at right-angles to the screw.

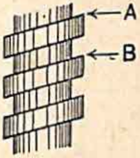


FIG. 57.

The advantage of a screw can be understood from some illustrative figures. If the pitch is $\frac{1}{8}$ in., the screw will advance $\frac{1}{8}$ in. for each turn. If the effort is applied at the end of a bar 6 in. long, it will move $2\pi \times 6$ in. for each turn. The velocity ratio is therefore $12\pi \div \frac{1}{8} = 302$. Although the efficiency of a screw is very low, because of excessive friction, this high velocity ratio is the basis of a large mechanical advantage.

A **car screw-jack** is shown diagrammatically in Fig. 58. Note how mechanical advantage is gained (*a*) by the leverage on the "tommy-bar," (*b*) by the cog-wheels A and B, (*c*) by the screw.

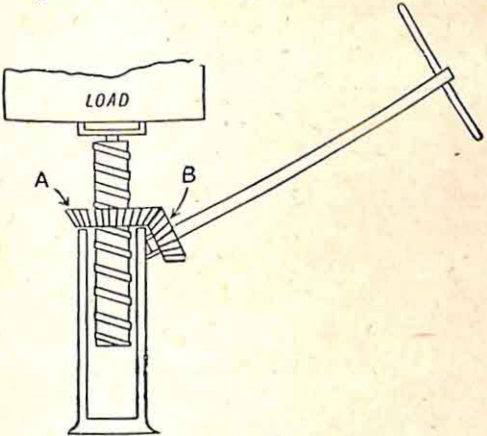


FIG. 58.

How fast can a machine work?

When we begin a car journey we assume that the engine is capable of doing the necessary work to overcome the resistance to motion, but we are interested to know how long the journey will take, i.e. *how quickly the engine can work.* The rate at which an engine can work is called its **power.**

Power = Rate of doing work.

It is measured in ft.-lb. per second or ft.-lb. per minute.

James Watt (p. 99) decided to compare the power of an engine with that of a horse. By testing the performance of horses he concluded that an average working horse can do 33,000 ft.-lb. of work per minute. This rate of working is called 1 horse-power (H.P.). Then a 20-H.P. engine can work at a rate of $20 \times 33{,}000 = 660{,}000$ ft.-lb. per minute. A man's power is about $\frac{1}{8}$ H.P., but, for a short period, he can work faster than this.

Problem.—An engine is required to pump water at the rate of 1,000 *gallons per minute to a height of* 66 *ft. At what H.P. must it work?*

1 gallon of water weighs 10 lb.

∴ 1,000 gallons of water weigh 10,000 lb.

∴ Work to be done per minute $= 10{,}000 \times 66$ ft.-lb.

∴ Power required $= \dfrac{10{,}000 \times 66}{33{,}000} = 20$ H.P.

CHAPTER 9

ENERGY

What is energy?

In Chap. 8 we learned that work is done when a force overcomes a resistance and so moves the point where it is applied. Any object or material which is capable of doing work is said to possess energy. **Energy is the capacity to do work.** We now study the different ways in which objects may possess energy.

The two chief forms of energy

A moving hammer drives in a nail against the resistance of the wood. Wind propels a sailing ship against the resistance of the water. Running water turns a water-wheel. A badly driven motor-car may demolish a wall. In all of these examples the agent (the hammer, the car, etc.) was able to do work because it was in motion. *All moving objects possess energy.* The energy possessed by objects because of their motion is called **kinetic energy**.

When a cricket-ball is thrown vertically into the air it possesses kinetic energy. At its highest point, however, it is momentarily at rest. What has happened to its kinetic energy? During its return towards the ground it regains its kinetic energy. From where has this energy come? We must conclude that *when an object is in such a position that it can fall it possesses energy*, for, as it falls, kinetic energy is acquired.

We wind up a clock-spring and it is then able to drive round the wheels and hands. The spring, *because of its constrained position*, possesses energy which becomes available as kinetic energy when the spring recovers its normal shape.

Any object which, because of its constrained position or shape, acquires kinetic energy when released, is said to possess **potential**

energy. We note that to give an object potential energy *work has to be done*, e.g. throwing the ball upwards, winding the clock-spring.

What is heat?

When a can of water is placed over a flame, "something" passes from the flame to the water, making the latter get hot. This "something" we call heat. We wonder, as scientific men did for many centuries, what this "something" is. In the eighteenth century it was supposed that heat was a mysterious fluid called "caloric." This could flow from one substance to another and fill the crevices between the particles of which the substances are made. When absorbed it could not be detected. Thus water (with its high specific heat) could absorb large quantities of caloric and yet not appear to get very hot, but when two rough surfaces were rubbed together some caloric was squeezed out and this surplus caloric caused a rise in temperature.

There are two important objections to this theory:

(1) A hot object does not weigh more than when cold and thus caloric must have no weight! Yet weight is an essential property of all substances.

(2) When a hole is drilled in a piece of metal *both* the drill and the metal get hot. Further, heat is continually produced for as long as the drill is worked. *The supply of heat is inexhaustible*, and it is absurd that the drill and the metal should contain an *unlimited* amount of caloric.

This was realised by Count Rumford who, in 1798, noted with surprise the high temperature of the chips of metal made during the boring of cannon. He conducted further experiments to determine the source of the heat and concluded that its production was entirely due to the *motion* of the borer.

In such experiments *work* has to be done to maintain the motion against the forces of friction. We remember that when work is done to lift an object, the object acquires potential energy. We agree that the metals must have acquired some form of energy as the result of the expenditure of work. But they gained heat. We conclude, therefore, that **heat is a form of energy**. This conclusion was accepted very slowly in spite of the experiments of Count Rumford. It was finally established by J. P. Joule who later proved that *the expenditure of a definite quantity of work produces a proportionate quantity of heat* (p. 108).

Heat, being a form of energy, must be capable of providing work when suitably harnessed. The steam engine and the steam turbine are convincing proofs of this capacity.

Steam engines

The honour of first applying steam to produce motion of a piston in a cylinder belongs to a Frenchman named Papin (1647–1714). His engine was not a practical success but its possibilities were realised by two Englishmen, Savery and Newcomen. They each devised steam engines for pumping water from mines. Their engines, however, were very inefficient for much of the heat derived from the fuel was not converted into work. The great engineer James Watt (1736–1819) devised better ways of making use of the heat and really made the steam engine a practical proposition.

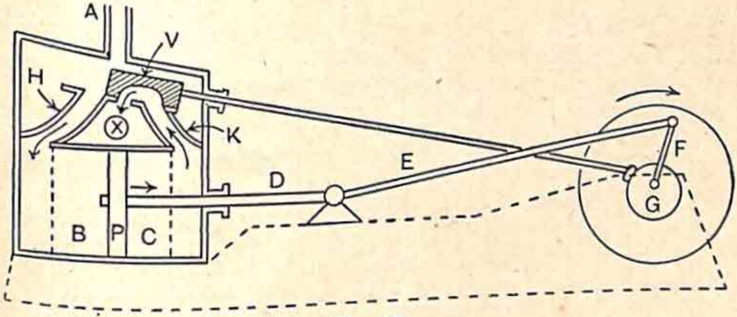
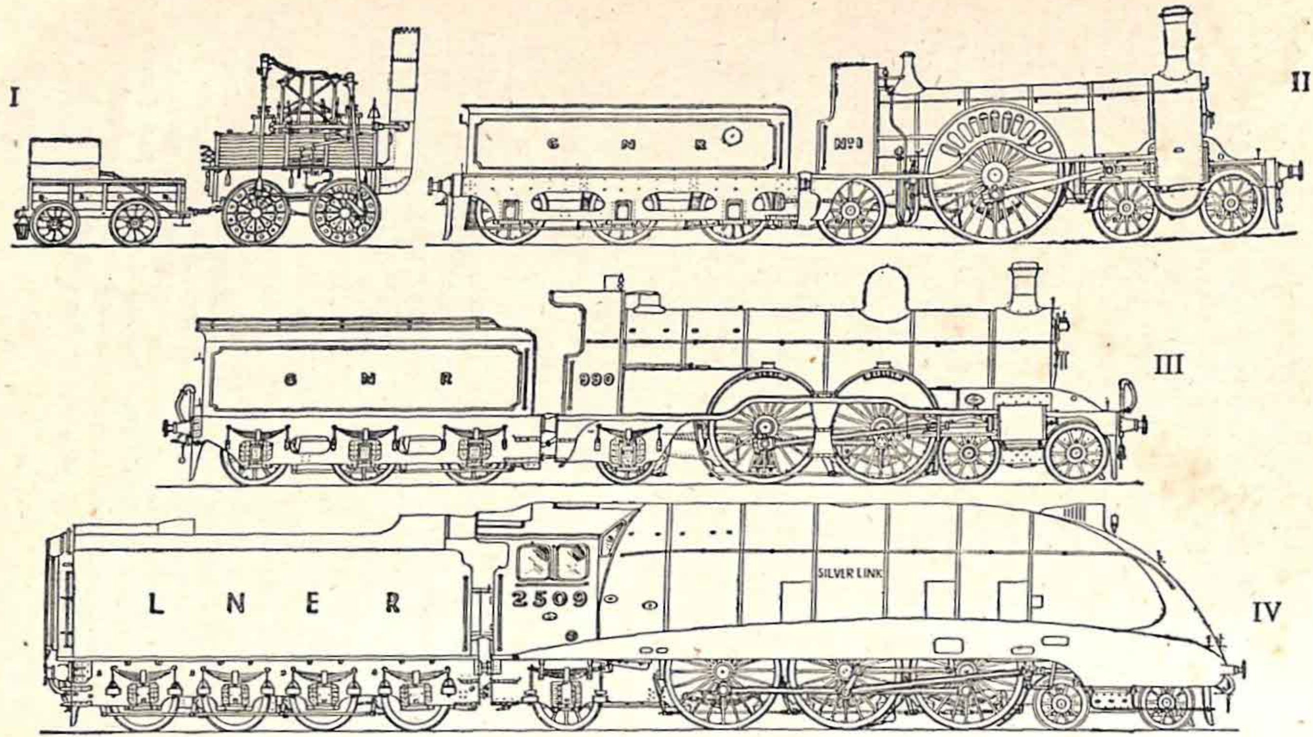


FIG. 59.

Fig. 59 shows, in diagrammatic form, the essential parts of a steam engine. The piston P moves in the cylinder between the dotted lines. The motion of the piston from one dotted line to the other is called a "stroke." During the forward stroke, steam admitted from the boiler by the inlet A, enters the cylinder at B through the "port" H. The pressure of the steam pushes the piston forwards, and, by means of the piston rod D, connecting rod E and crank F, the wheel is turned. During this stroke the port K is kept closed by the slide-valve V. Towards the end of the stroke this valve


I
II
G N R
No 1
III
G N R
990
IV
L N E R
2509
SILVER LINK

EVOLUTION OF THE LOCOMOTIVE.

I. " Locomotion." Weight 15 tons 5 cwt. Length 23 ft. 6 in. II. G.N.R. No. 1. Weight 64 tons 19 cwt. Length 52 ft. 3½ in. III. G.N.R. No. 990. Weight 98 tons 18 cwt. Length 57 ft. 1 in. IV. L.N.E.R. Silver Link. Weight 165 tons 7 cwt. Length 70 ft. 3¾ in.

is pushed over, by means of the eccentric disc G, to close port H and then to open port K. Steam is now admitted into the cylinder at C and its pressure drives the piston back towards B and continues the rotation of the wheel. It also drives the spent steam used in the forward stroke back through the port H into the exhaust X from which it escapes.

By employing steam at high pressure, Trevithick and Stephenson each devised locomotives to draw coal wagons. The latter was the first builder of a passenger locomotive and when, in 1829, he constructed *The Rocket* the future of steam railways was assured. By 1850, 5,000 miles of British railways were in use.

In all steam engines much of the heat energy is wasted (p. 109). In addition to wastage by mechanical imperfections, a large quantity of heat is rejected in the steam which escapes by the exhaust. In stationary engines some of this rejected heat is used again in the heating of the water before it enters the boiler.

Steam turbines

Steam turbines, which are fitted extensively in large ships and in electric power stations, also use steam as the "working substance" in the conversion of heat energy into kinetic energy, but employ a different principle. The main shaft carries a number of rings from the edges of which projects a set of curved blades. Between each pair of rings is another set of blades, but curved in the opposite direction, fixed to the inside of the turbine casing (Fig. 60). When steam, at high pressure impinges on the movable blades, the shaft is caused to rotate. The fixed blades guide the steam so that it strikes the movable blades at a suitable angle. The compartments

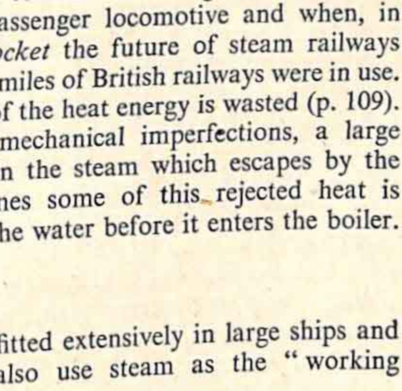


FIG. 60.

containing the blades are successively larger to allow for the expansion of the steam as its pressure falls.

Chemical energy

We now resume our enquiry of the different forms of energy. Although heat can be produced by mechanical means, that utilised by a steam engine is obviously derived from the fuel. Does the fuel possess energy? We decided that a wound-up clock-spring possesses energy, for, under suitable conditions, it can yield energy. We must similarly decide that fuel possesses energy. The energy in fuel is clearly *potential*, but as it is released by the chemical action of burning, it is more convenient to distinguish it as **chemical energy.**

Chemical energy can only be released by suitable chemical reactions. The usual reaction is oxidation. The burning of coal, oil and coal-gas are familiar examples. If a mixture of aluminium and iron oxide is once ignited, e.g. by a magnesium fuse, chemical action will take place and sufficient heat will be liberated to raise the temperature of the mixture to over 2,500° C. This mixture is called " thermite " ; it forms the central part of an incendiary bomb.

We have learned that carbohydrates and fats are essential foods. They are "energy-giving" foods for, by their slow oxidation, animals obtain muscular (kinetic) energy and body heat. Plants require less energy, but we have already noted (Book I, p. 193) that seeds generate heat by respiring.

Some chemical actions produce a large quantity of hot gas very quickly. The gas, by its rapid expansion, can produce violent motion. Such reactions are called *explosions*. The chemical energy is effectively converted into kinetic energy, though some is released as heat. The use of explosives in firing a gun is a good example.

The controlled explosion of petrol vapour and air is utilised in the **internal combustion engine** (e.g. in motor-cars, aeroplanes and tanks). In a motor-car engine there are usually four cylinders and four pistons operating on one crankshaft. Fig. 61 *a* shows, in diagrammatic form, one cylinder C, piston P and accessories. A mixture of petrol spray and air is delivered by the carburettor (not shown) to the cylinder. The entry is controlled by a valve, operated by a rotating cam, and a similar valve controls the exit of the exhaust gases. The explosion is brought about by means of an electric spark between metallic points of a sparking plug (Fig. 61 *b*). The cycle in a normal "four-stroke" engine is as follows: 1st stroke (shown in Fig. 61 *a*), piston moves downwards, petrol mixture enters cylinder; 2nd stroke, piston moves upwards and compresses mixture, which is fired just before top of stroke; 3rd stroke, piston pushed downwards; 4th stroke, piston moves upwards and expels exhaust gases. The pistons, cams and spark are arranged so that the power stroke (3rd) occurs successively in different cylinders.

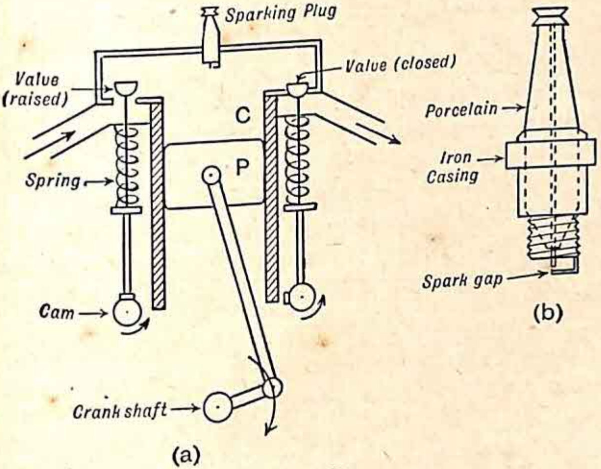


FIG. 61.

Other forms of energy

The electric motor is another machine which develops kinetic energy. The source of this energy is the current which flows in the armature mounted in a powerful magnetic field (Book II, p. 100). We therefore conclude that energy is associated with the flow of electric current and we speak of it as **electrical energy**. The action of the dynamo shows that the conversion of electrical energy into kinetic energy is reversible.

A magnetic field also possesses energy, for, when a piece of magnetic substance is placed in it, the substance experiences a force which may make it move. Such energy is called **magnetic energy.** During an explosion, **light** and **sound** are usually produced in addition to heat and kinetic energy. We must add these to our list. It is not easy to demonstrate that light can do work, but delicate experiments show that it exerts a pressure. We appreciate the association of kinetic energy with sound when a thunder-clap makes our windows rattle, and the screech of sharply applied brakes illustrates the reverse process.

Transformation of energy

You can now make a list of the different forms of energy. We have seen that all can be converted into kinetic energy and that, in some cases, the process is reversible. We now enquire whether other transformations are possible. All forms of energy are liable to turn into heat energy, e.g. electrical energy is transformed into heat energy in an electric radiator, but, with suitable control, other transformations may be effected.

(1) The photo-electric cell, which forms the essential part of an electrical photographic exposure-meter, transforms light into electrical energy.

(2) A loudspeaker effectively transforms electrical energy into sound.

(3) Light is transformed into chemical energy when a photographic plate is exposed.

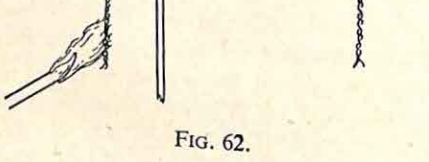


FIG. 62.

(4) The transformation of heat into electrical energy is shown in the following experiment.

Expt. A.—Join a piece of bare Eureka wire (30 cm.) at each end to lengths of bare copper wire by tightly twisting together the ends. Support the Eureka wire in a wooden clamp and join the free ends of the copper wires to a milli-ammeter or milli-voltmeter (Fig. 62). Heat one of the junctions with a Bunsen flame and observe the deflection of the needle of the instrument.

This list is by no means exhaustive. It is instructive to think out other transformations.

One form of energy may be transformed into more than one other form. Thus, in the percussion of a pneumatic drill on rocky ground, kinetic energy is transformed into heat, light and sound energy.

Electric cells

Although chemical energy is usually transformed into heat, it is possible *under suitable conditions* to transform it into electrical energy. This direct transformation is the basis of the working of electric (or voltaic) cells.

Expt. B.—To investigate the conditions for the transformation of chemical energy into electrical energy.

(*a*) Two zinc plates are stood apart in a jar of dilute sulphuric acid. Wires attached to the top of each plate are connected to the terminals of a voltmeter. Hydrogen is evolved at the surfaces of the plates but no voltage is registered.

(*b*) Two copper plates are substituted for the zinc plates and the circuit again completed through the voltmeter. There is neither voltage nor chemical action.

(*c*) One zinc plate and one copper plate are now used, and the circuit completed as before. Bubbles of hydrogen are evolved, as expected, at the surface of the zinc, *but are also seen adhering to the copper plate.* The voltmeter registers about 1 volt.

In (*a*) the energy released by the chemical action of dilute sulphuric acid on zinc appears as heat. For the energy to be released in the electrical form we require, as shown in (*c*), two unlike plates joined externally to complete the circuit. The arrangement of a zinc and a copper plate in dilute sulphuric acid forms a simple cell.

Expt. C.—To study the defects of a simple voltaic cell.

(*a*) The simple cell is connected in series with a small rheostat and an ammeter. The latter indicates a current. The circuit is broken and, as is expected, the current ceases, *but hydrogen is still evolved at the zinc plate.* The zinc continues to dissolve, but, as no electrical energy is produced, the metal is being wasted.

This waste is avoided by "amalgamating" the zinc plate, i.e. rubbing it with mercury. This renders the zinc ineffective *except when the circuit is closed* and also improves the working of the cell.

(*b*) The cell is reconstructed with an amalgamated zinc plate and the circuit remade. The current is allowed to flow for some minutes and the ammeter reading observed. The current falls, indicating that the cell is losing its effectiveness. This defect, called **polarisation**, is due to the accumulation of hydrogen on the copper plate.

(*c*) A solution of potassium dichromate or potassium permanganate is added to the polarised cell. The cell recovers its activity and, providing its ingredients are not used up, maintains its activity. This process removes the hydrogen by chemical means. Other chemical means of preventing or reducing polarisation are found in the two following common cells.

The Daniell cell (Fig. 63) employs copper sulphate solution to prevent polarisation. The solution is separated from the acid by a *porous* pot, but, as the liquids slowly mix, the cell is only suitable for temporary use. The voltage is steady and about 1·1 volts.

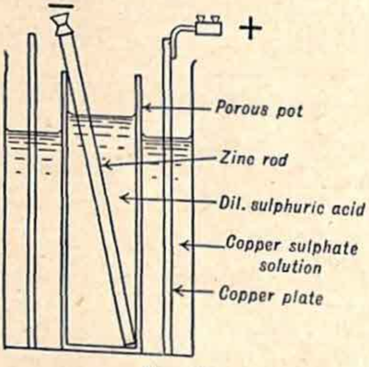

−
+
Porous pot
Zinc rod
Dil. sulphuric acid
Copper sulphate solution
Copper plate

FIG. 63.

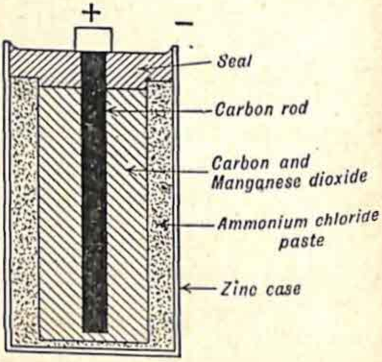

+
−
Seal
Carbon rod
Carbon and Manganese dioxide
Ammonium chloride paste
Zinc case

FIG. 64.

The Leclanché cell depends upon the release of energy when zinc dissolves in ammonium chloride (sal-ammoniac) solution. The action can be represented as follows :

$$Zn + 2NH_4Cl \rightarrow ZnCl_2 + 2NH_3 + H_2.$$

The hydrogen, which collects around the positive electrode, tends to cause polarisation. This electrode is a carbon rod, mounted in a porous pot, and packed around with carbon and manganese dioxide. The latter substance removes the hydrogen, but, as its action is slow, the cell cannot produce a large current for an extended time.

For high-tension batteries and torch batteries, " dry " Leclanché cells are used. The ammonium chloride solution is absorbed in sawdust or plaster of Paris and the porous pot replaced by a thin cardboard case. The outer zinc case forms the negative electrode (Fig. 64).

The lead accumulator

Expt. D.—To demonstrate the mode of action of a lead accumulator.

Two lead plates are supported in a jar of dilute sulphuric acid (sp. gr. 1·2) and the voltameter connected, as shown in Fig. 65, to form part of two circuits. Circuit X includes a rheostat, ammeter and 30-volts D.C. mains, and circuit Y a voltmeter. Either circuit can be closed by means of the double-throw key K.

First circuit Y is closed. The voltmeter registers zero. Circuit X is then closed and a current of about 2 amps. allowed to flow for about 10 minutes. Gas is evolved at the cathode and the anode acquires a brownish colour. The key is then moved to close circuit Y and the voltmeter indicates about 2 volts. If the voltmeter is replaced by an electric bell. the latter rings for several minutes.

At first no voltage is registered for both plates are alike. When circuit X is closed, the chemical action of the current causes the anode to become coated with brown lead peroxide (PbO_2) but the cathode is unchanged. *The plates are now unlike*, and, by the dissolving of the lead plate in the acid, we have the conditions for a cell. When this cell produces a current, however, further chemical changes occur. The

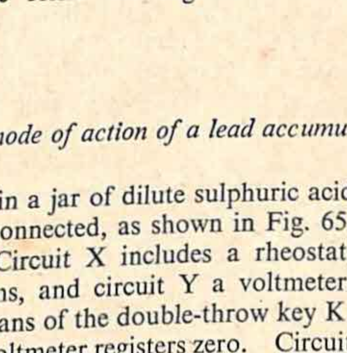


FIG. 65.

in his leisure hours.) Fig. 66 shows diagrammatically the apparatus he used for many of his experiments. A measurable quantity of work was done by lead weights W_1 and W_2 which, by their slow descent on cords, turned the discs D and hence the paddles P in a calorimeter C. The paddles, churning the water in the calorimeter, converted the work into heat. The quantity of heat produced was determined from a knowledge of the thermal capacity of the water and the calorimeter and the temperature rise.

As a result of all his experiments, remarkable for their variety and accuracy, Joule concluded that **the production of 1 B.Th.U. of heat requires the expenditure of a DEFINITE quantity of work.**

$$\frac{\textbf{Useful work done by engine}}{\textbf{Mechanical equivalent of heat value of fuel used in that time}}$$

Compare this definition of efficiency with that for a simple machine (p. 94).

Example.—In a certain steam engine, $3\frac{1}{2}$ lb. of coal (of calorific value 10,000 B.Th.U. per lb.) are used per hour for each horse-power developed. What is the efficiency of this engine?

∴ Heat supplied per hour (per H.P.)

$$=10{,}000\times3\tfrac{1}{2}=35{,}000 \text{ B.Th.U.}$$

∴ Mechanical equivalent of heat supply per hour

$$=35{,}000\times778 \text{ ft.-lb.}$$

plates gradually become coated with the same chemical (lead sulphate) and eventually the cell's activity ceases.

In the lead accumulator the plates are specially prepared so that the formation of lead peroxide is very efficient. While the accumulator is **charging,** i.e. a current is passed through from an external source, electrical energy is being transformed into chemical energy. When it is **discharging**, i.e. producing its own current, the reverse transformation takes place. The accumulator, however, is never allowed to become completely discharged.

The steady voltage (2 volts) and very small internal resistance make this accumulator a convenient and efficient low voltage source, but its weight and the corrosive nature of the acid are disadvantages.

Can we profit by energy transformations?

Is there any gain or loss of energy when one form is changed into another? We can buy an article (i.e. exchange money for it) and then, by selling it at a higher price, make a profit. There could be no profit if the price were fixed. To test whether we can gain or lose energy by transformations we must find, by experiment, whether a certain quantity of one form always gives by a complete transformation a *definite* quantity of another form.

Dr. J. P. Joule began, in 1840, a series of experiments to test "the rate of exchange" when mechanical work is converted into heat. (He was a brewer and his experiments provide the classic example of scientific achievement attained by a man working in his leisure hours.) Fig. 66 shows diagrammatically the apparatus he used for many of his experiments. A measurable quantity of work was done by lead weights W_1 and W_2 which, by their slow descent on cords, turned the discs D and hence the paddles P in a calorimeter C. The paddles, churning the water in the calorimeter, converted the work into heat. The quantity of heat produced was determined from a knowledge of the thermal capacity of the water and the calorimeter and the temperature rise.

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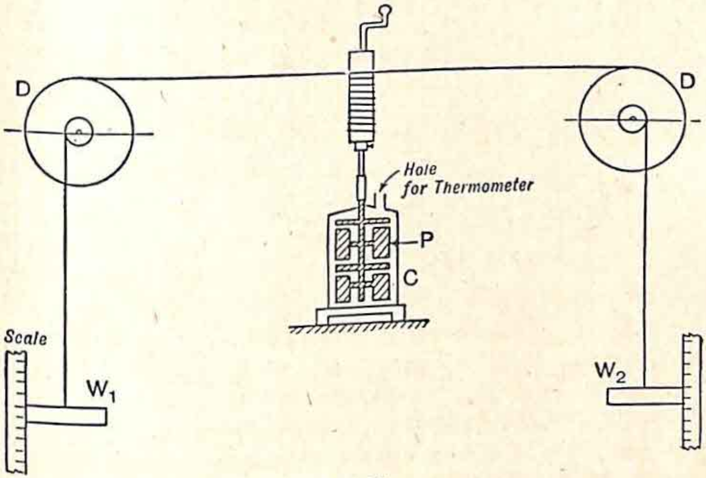

FIG. 66.

The accepted value for the "rate of exchange," since measured by many scientists, is

778 ft.-lb. are equivalent to 1 B.Th.U.

This figure (or its corresponding value in metric units) is called **the mechanical equivalent of heat.**

The efficiency of heat engines

We define the efficiency of an engine which converts heat into work as

$$\frac{\textbf{Useful work done by engine in a given time}}{\textbf{Mechanical equivalent of heat value of fuel used in that time}}.$$

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$$=10{,}000\times3\tfrac{1}{2}=35{,}000 \text{ B.Th.U.}$$

∴ Mechanical equivalent of heat supply per hour

$$=35{,}000\times778 \text{ ft.-lb.}$$

But 1 H.P. is 33,000 ft.-lb. per minute.

$\therefore$ Useful work done per hour $=33{,}000\times 60$ ft.-lb.

$$\therefore \text{Efficiency}=\frac{33{,}000\times 60}{35{,}000\times 778}=0{\cdot}07 \text{ or 7 per cent.}$$

This example shows that the efficiency of a steam engine is very low (usually 5–10 per cent.). The engine is thus very wasteful. The efficiency of an internal combustion engine is rather greater, and that of a Diesel oil engine approaches 40 per cent.

The rate at which electricity can do work

To drive a quantity of electricity through a circuit, a voltage (or pressure difference) is required. This voltage does work in driving the electricity against the resistance of the circuit. The work is derived, of course, from the energy of the source.

The quantity of electricity which passes round a circuit is measured in **coulombs** and 1 coulomb has passed when 1 ampere has flowed for 1 second. Thus

Coulombs = amperes × seconds.

A certain quantity of work will be done to drive every coulomb of electricity from one point to another in a circuit. When the two points are such that the voltage between them is 1 volt, the work done, for each coulomb, is called 1 **joule**. Then

Work done in joules = coulombs passed × voltage
= amperes × seconds × voltage.

Thus if a pressure of 200 volts drives a current of 0·3 amps. through a lamp for 30 seconds, work done $=200\times 0{\cdot}3\times 30$ $=1{,}800$ joules.

Note.—Since the ampere and the volt are metric units, a joule is a metric unit of work. It is approximately $\frac{3}{4}$ *ft.-lb.*

It is important to know the *rate* at which work is done, i.e. the power (p. 96). It follows from the last equation that the work done per second is given by amperes × voltage. Thus

joules of work done per second = amperes × volts.

A rate of 1 joule per sec. is usually called 1 **watt**. Thus the lamp taking 0·3 amps. at a pressure of 200 volts consumes

$200 \times 0{\cdot}3 = 60$ joules of energy per second, or consumes *at the rate of* 60 watts.

Note.—The watt is a metric unit of power. 746 *watts*=1 *H.P.* =550 *ft.-lb. per sec.*

Heat produced by a current

The work which is done when the current flows is converted into heat (and sometimes light). The " rate of exchange " is, of course, that previously discussed, in fact Joule and other scientists have checked the value by the heating effect of a current, but it must be expressed in metric units. It is

4·18 joules are equivalent to 1 calorie.

This value can be tested with an apparatus similar to Fig. 16, p. 30. A voltmeter must be attached across the terminals of the heating coil and pure (not tap) water is used in the flask. By measuring the voltage, the current and the time for which it flows, the work done (in joules) is calculated. From the knowledge of the temperature rise and the thermal capacities of the water and the flask, the heat produced (in calories) is determined. Then the number of joules which produce 1 calorie can be found by division.

It is important to realise that this " rate of exchange " is merely the metric equivalent of that learned before, i.e. 778 *ft.-lb. per B.Th.U.*

Watts, " units," and electricity bills

Every householder who buys an electric iron, radiator, cooker, etc., is interested to know what it will cost to use. The energy, in joules, taken by the appliance can be calculated by multiplying the watts by the number of seconds for which it is used, but this product gives a large and unwieldy number. It is more convenient to take as our units a power of 1,000 watts (i.e. 1 kilowatt) and a time of 1 hour. **The energy taken at the rate of 1 kilowatt for 1 hour is called 1 kilowatt-hour or 1 Board of Trade Unit.** We are charged according to the number of such " units " taken.

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Example (1).—For how long can a 60-watt lamp be used to take 1 B. of T. Unit?

1,000-watt appliance can be used for 1 hour.

$\therefore$ 60-watt appliance can be used for $\frac{1,000}{60}=16\frac{2}{3}$ hours.

Example (2).—A 2-kilowatt electric radiator is used for 5 hours. What is the cost at 1*d.* per "unit"? How much heat will it give per minute?

Energy taken $=2\times5=10$ kilowatt-hours $=10$ "units."

$\therefore$ Cost at 1*d.* per "unit" $=10d.$

Rate of working $=2,000$ watts $=2,000$ joules per sec.

$\therefore$ Rate of production of heat $=\frac{2,000}{4\cdot18}$ calories per sec.

$\therefore$ Calories produced per minute $=\frac{2,000\times60}{4\cdot18}=28,700.$

No profit, no loss

The investigation begun by Joule, and subsequently extended by other scientists, show that all energy transformations are subject to fixed "rates of exchange." There can therefore be no gain or loss of energy as the result of transformations. This fact is called the **Principle of Conservation of Energy.** It can be stated thus: **Energy cannot be created or destroyed but only changed from one form into another.** It is clear now why the efficiency of a machine cannot exceed 100 per cent. and why, in calorimeter experiments, heat gained = heat lost.

We may compare this important *physical* principle with an equally important *chemical* principle. The nitrogen and carbon cycles (pp. 68, 25) illustrate that matter (i.e. substance) cannot be created or destroyed, but only changed from one form into another. This fact is called the **Principle of Conservation of Matter.**

The sun, green plants and ourselves

Although energy cannot be destroyed, it can be wasted and rendered useless. Thus, of the energy supplied to a dynamo, some is converted into heat by friction at all moving parts and so becomes of no value. The electrical energy produced will ultimately become heat in the wires and appliances through which the current flows. All energy ultimately turns into heat. Even if a steam engine could be made to work with such scattered heat it would not succeed in converting *all* of it back into useful work, and so our terrestrial supply of energy is gradually becoming of no value. Can we get a new supply?

From what source does our muscular (kinetic) energy come? The carbohydrates which supply us with energy are made by green plants (carbon-assimilation, p. 24). *In this process sunlight is absorbed.* The carbohydrates derive their energy from the sun's radiation. The SUN, therefore, supplies our energy and green plants trap it for us. We depend upon the mighty sun and the humble green plants for our very existence.

For many of our comforts and activities we utilise the chemical energy in coal. Coal seams are the compressed remains of ancient vegetation and the carbon which they contain is derived from the carbohydrates made when the plants were living. Thus, again, the energy originally came from the sun.

The winds (possessing kinetic energy) blow because of pressure differences in the atmosphere. These pressure differences are caused by unequal heating by the sun. The energy of running water, utilised in hydro-electric turbines (p. 161), is again derived from the sun, for the sun's heat evaporates water from the earth's surface and ultimately rain falls, partly on the high ground.

We learn, therefore, that in various ways, new supplies of energy are obtained from the sun.[1] You will probably ask: From where does the sun get its energy? That is one of the problems of science which has not been adequately solved.

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[1] The energy of the tides, due chiefly to the moon's influence, is the only practical exception.

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CHAPTER 10

WAVES AND WAVE MOTION

A new type of motion

We all know that when a stone is thrown into a pond of still water ripples spread outwards from the point of contact, and that these ripples become more feeble as their diameters increase. Similarly, if a long heavy rubber cord [1] be suspended to hang vertically and its lower, free end be given a sharp jerk sideways, a ripple travels up the cord to the fixed end and is reflected back to the free end. In each of these instances we observe a new type of movement, viz., a motion continued from part to part of a substance, without the substance moving as a whole from one place to another. This is clearly seen in the rubber cord which does not rise as the ripple moves upwards, nor fall as it is reflected downwards. In the case of the water ripple, the fact that the water does not flow with the ripple may not be so evident, but it may readily be shown by using a ripple tank (Fig. 67). [*Whatever form is used, the essential features of this piece of apparatus are the same—a tank of water of uniform shallow depth, a source (or dipper) to disturb the surface as the stone disturbs the pond, and, for convenient observation, optical arrangements for projecting the results of the disturbance on a screen.*]

Expt. A.—The tank is set up and a few shavings, cut from a small cork, are scattered at random on the surface of the water. The ripples are started and the course of any one observed. As it spreads from its source to the sides, the cork floats rise and fall as the ripple passes each one; no float moves with the ripple towards the side. We note, therefore, that whilst the water at the surface moves up and down, a disturbance passes across this surface without any actual flow of water.

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[1] 12 to 15 feet of pressure tubing make an effective substitute.

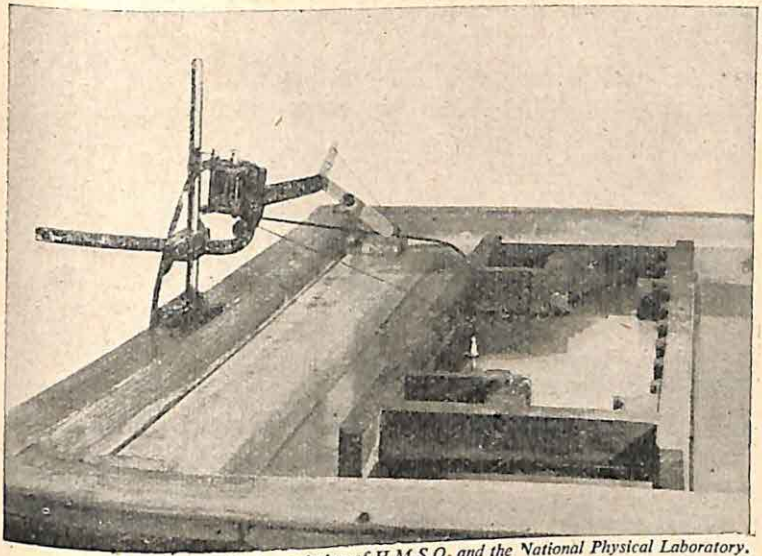

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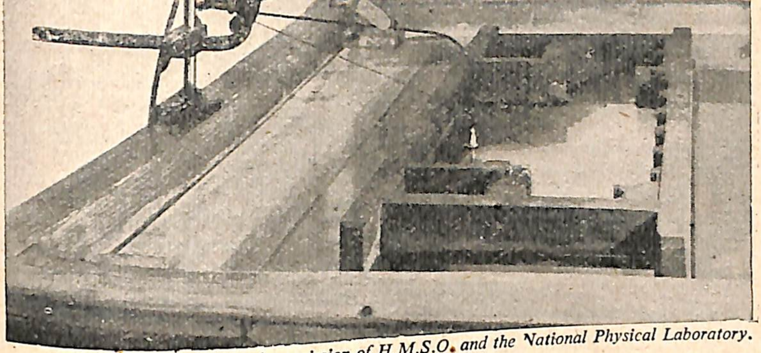
FIG. 67.—RIPPLE TANK.

Transverse wave motion

The source which starts the ripple is moving; it therefore possesses kinetic energy and some of this energy is given to the substance in contact with it. But the whole of the substance does not respond at once, as would a cricket-ball struck by a bat; instead, energy is accepted only in the region of contact and only gradually is this energy passed on to neighbouring parts of the substance. This *transference of kinetic energy* across the surface of the water causes successive parts of it to move; in turn, each part copies the motion of the water from which it received this energy. In the first instance, the action of the source is to cause a down-and-up movement of the water (for the water cannot remain depressed). But the water returning from its depressed position arrives at its original position in possession of kinetic energy and continues to move upwards, coming momentarily to rest at a point above its undisturbed position. The water is thus set in oscillation, but this quickly dies away owing to the transfer of energy and to resistance



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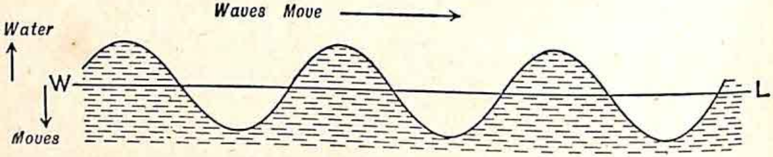

Fig. 68.

If the source is kept continuously in operation, wave follows wave to the sides of the tank and this procession of waves is called a **wave train.** In these examples, the actual movement of any portion of the water or cord taking part in the transfer of energy is at right angles to the direction of motion of the waves. Such waves are called **transverse waves**, and their movement, **transverse wave motion.**

Terms and definitions

In Fig. 69, the straight line WL shows the undisturbed water line of the section taken. When the wave train is advancing, any particle of the wave form situated at any instant on this line is said to be in its *mean position*. Nearly all the particles in the wave form are either above or below this line and they are moving towards or from it as the waves advance. The distance at any time of any particular particle from its mean position is called its **displacement**, e.g. AP is the displacement of the particle P which was originally at A.

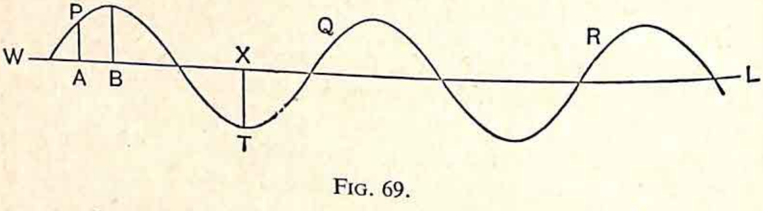

Fig. 69.

During one complete oscillation of any particle, this displacement, which is constantly varying, reaches a maximum once on each side of the mean position, e.g. the particles C and T whose mean positions are respectively B and X. This maximum displacement is called the **amplitude**. The elevated and depressed portions of the wave form are usually referred to as crests and troughs.

In each successive wave of a train of waves there are particular particles, e.g. P, Q and R, whose displacements, speeds and directions of motion are precisely the same. The motions of such particles are said to be in the *same phase*. The straight distance between two *consecutive* particles in the same phase is the **wave-length.**

Each particle repeats the motion of its oscillation in the same time, known as the *periodic time*. Since successive particles copy this motion, the number of oscillations completed in 1 second by every particle of the wave train is the same. This number is the **frequency**.

As the wave form advances there is no bunching together or separation of individual waves. Thus the disturbance travels with uniform speed, called the speed or **velocity of propagation.** If λ=wave-length, N=the frequency and V=the velocity of the waves, in a distance V, traversed by the waves in 1 second, there will be N waves because each particle has completed N oscillations in 1 second, and each wave will be of length λ.

Hence $V=N\lambda$.

Transverse wave motion in practice

The examples of transverse wave motion studied earlier were chosen to demonstrate its essential features, but, in everyday life, other transverse wave motions are of greater importance. The motion of the strings of a pianoforte, a violin or a harp is a transverse wave motion. We do not see the familiar wave shape, because both ends of the string are rigidly fixed and the waves are being constantly reflected from each end and superimposed on each other.

Wireless waves are also transverse. It is difficult to picture their transmission for, unlike the other waves which we have studied, no material substance is needed to carry them. (*They may travel through air, but they do not use it in their transmission.*) Using simple apparatus, we concluded that light and radiant heat travel in straight lines, yet there is evidence of an advanced character which points to the transmission of these forms of energy as transverse waves of very short length. X-rays, too, are really transverse waves.

These waves, which do not require a material substance to carry them, are electrical in nature and are collectively called **electro-magnetic** waves. All travel with the same velocity, which must be that of light, viz., 3×10^{10} cm. per sec. or 300,000 kilometres per sec., and are distinguished from each other in wave-length and frequency and by the characteristic effects which they produce. The wave-lengths of X-rays are extremely short, those used in Radiology ranging from 0·0000000006 cm. to 0·000000005 cm. Light waves vary in length according to the colour they produce, ranging approximately from 0·00004 cm. to 0·00008 cm. as we cross the spectrum from its violet to its red end. Waves slightly shorter than those of violet light are detected by photographic and chemical action; they are known as ultra-violet waves. The shortest wave-lengths of radiant heat transmission overlap the red end of the spectrum; beyond this the waves are classified as infra-red and increase in length to about 0·01 cm. as the temperature of the radiating source decreases.

Wireless waves are much longer and spread over a great range of wave-length. To-day, for public transmissions, there are three "bands" (or ranges); short, medium and long waves, the gaps being reserved for special services. Frequencies in kilocycles and wave-lengths in metres are printed in most wireless handbooks. One example here will show how the information has been reduced for convenience to these forms of statement. Daventry broadcasts on a wave-length of 1,500 metres with a frequency of 200 kilocycles.

The velocity of transmission is 3×10^{10} cm. per sec.
which is equal to 3×10^{8} metres per sec.

From $V = N\lambda$, for a wave-length of 1,500 metres
we have $3 \times 10^{8} = N \times 1{,}500$
i.e. $N = 200{,}000$ cycles or 200 kilocycles.

Clearly, statements of 1,500 metres and 200 kilocycles are more convenient for everyday use than the corresponding figures of 150,000 cm. and 200,000 cycles.

Sound and sounding sources

When a stimulus, called a *sound*, is applied to the ear, nerve messages communicate its arrival to the brain and we experience the sensation of hearing. The source of this stimulus may always be traced to the vibration of some body, although such vibrations are often too feeble to be seen and always too rapid to be counted by the human eye. That the ultimate sounding source is in a state of vibration is shown by the following experiments.

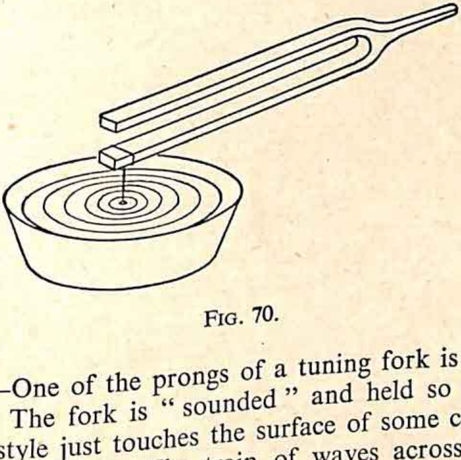

FIG. 70.

Expt. B.—One of the prongs of a tuning fork is fitted with a wire style. The fork is "sounded" and held so that the free end of the style just touches the surface of some clean mercury in a bowl (Fig. 70). The train of waves across this surface clearly reveals the continuous vibration of the prong of the fork.

The sounding source need not be a solid.

Expt. C.—An organ pipe is connected to a wind chest and blown gently. While the pipe is sounding, a light tray of stiff paper carrying a few grains of *fine, dry* sand is lowered into position over the mouth of the pipe (Fig. 71). The bounding action of the sand indicates that the paper is in vibration; that this is due to the vibration of the air beneath and not to any flow of air through the pipe is shown by detaching the pipe and allowing air from the wind chest to play on the under side of the tray.

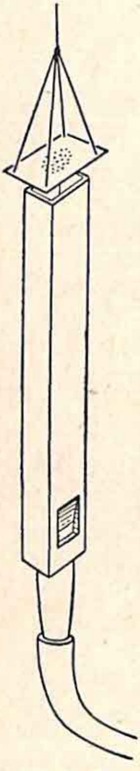

FIG. 71.

From sounding source to the ear

Quotation from Book II, p. 225, describing a trip to the moon: " No sound would be heard and unless we could provide some sort of local atmosphere it would be quite useless to talk to each other."

Evidently the atmosphere plays an important part in transmitting a sound from its source to the listener. This is shown by enclosing a sounding source, e.g. an electric bell, in a bell-jar mounted on the receiver of and exhausted by a Geryk pump.[1]

Expt. D.—The bell is suspended from the under side of the rubber stopper of the bell-jar and two fine, coiled copper wires passing through the stopper connect the terminals through a switch to a dry cell (Fig. 72). The jar is mounted on the *well greased* plate of the receiver which is connected through the stop-tap to the pump. The switch is closed to test the loudness of the bell. The switch and tap are opened and the jar exhausted as highly as possible ; the tap and switch are closed and the pump disconnected.

We can see the trembler of the bell in motion, but we do not hear the ring or only hear it very faintly. Leaving the switch closed, the tap is opened slowly and, as more and more air enters, a well-marked increase in the volume of sound is heard. The only change has been the introduction of the air, so we may fairly conclude that it was necessary in this experiment for the transmission of the sound.

The same result would be obtained if any other gas were allowed to enter the bell-jar. Solids and liquids can also serve as agents of sound transmission. The ticking of a watch is heard plainly if the watch is pressed firmly against the forehead. Here the solid materials of the watch and the bones of the head are the substances through which the sound travels to the ear. A faint scratch on one end of a long bench is usually inaudible to everybody in the laboratory ; yet it may be heard distinctly by a listener who places his ear in contact with the remote end of the bench. The explosion of a depth-charge affords clearly heard evidence that sound travels in water.

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[1] The use of an efficient pump is all important ; the pressure should be reduced to the order of 1 to 2 mm. of mercury.

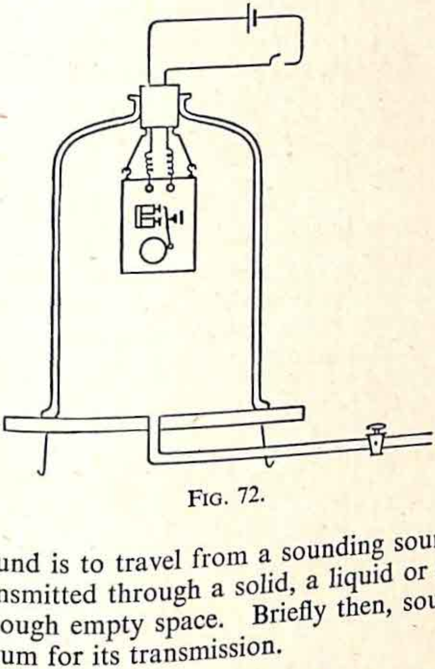

FIG. 72.

Thus, if sound is to travel from a sounding source to the ear, it may be transmitted through a solid, a liquid or a gas ; it will not travel through empty space. Briefly then, sound requires a material medium for its transmission.

How sound is transmitted

(1) **Introductory.**—Sound is transmitted through all media by the same process. As the most widely used medium is the air, we shall confine our attention to its behaviour. As the vibrating source presses against the air near it, there is slight compression

of this air; as the source recedes there is slight expansion (or rarefaction) of this same air, for the to-and-fro motions of the vibrator follow so quickly that there is not time for the air to be pushed out of the way. One end A of a long, horizontal spiral spring (Fig. 73) may be similarly compressed or stretched by applying a slight but sudden push or pull at that end. By observing how these compressions and stretchings affect the rest of the spring we shall understand how the compressions and rarefactions produced near the vibrator affect the air and so transmit energy from the source to the receiver.

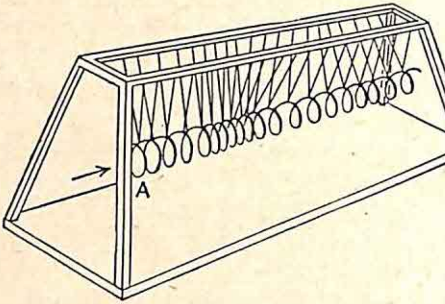

FIG. 73.

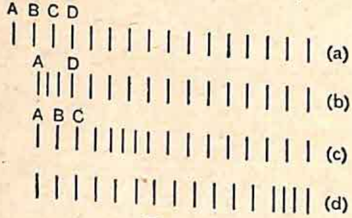

FIG. 74.

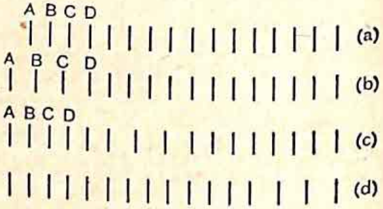

FIG. 75.

(2) **A new type of wave motion.**—The strokes A, B, C, D . . , Fig. 74 (*a*), represent adjacent turns of the spring. If A is pushed forward *suddenly* only the few turns near this end are compressed (*b*). But the spring cannot remain permanently in this condition and the recovery of A, B, C causes the neighbouring turns to be compressed (*c*). Thus, in time, this state of compression of a few turns passes from one end to the other (*d*).

Or if A be suddenly pulled back the turns A, B, C are slightly separated and this state of separation passes, in time, along the spring (Fig. 75). In both instances, the spring as a complete body does not perceptibly alter its position ; the energy given to the end turn A is passed on to successive turns, causing each to copy the motion of the turn from which it received this energy. But during this transfer of energy, the parts of the substance move in directions which are parallel to the direction of transfer. This constitutes a second type of wave motion ; because of the similarity of direction of motion of the matter and the wave, it is called **longitudinal wave motion.**

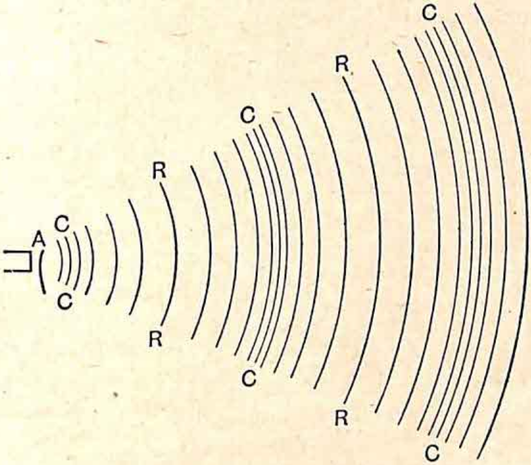

FIG. 76.

(3) **Sound waves in air.**—When a sounding source vibrates, e.g. the diaphragm of a loud speaker, the air in front of it is alternatively compressed and rarefied just as the end turns of the spring were compressed and separated by pushing and pulling that end. But whereas the compressions and separations of the turns travel only along the line of the spring, the compressions and rarefactions of the air travel outwards from the source in all directions. We may picture these compressions and rarefactions as spherical shells expanding as they travel out from

the source. But the air, *as a whole*, does not flow with the compressions and rarefactions. With the vibrator continuously in action (Fig. 76), compressions C and rarefactions R of a longitudinal wave train pass through the air at equal intervals, just as crests and troughs of a transverse wave train advance over the surface of water.

Both types of wave motion involve a transfer of energy by means of vibrating particles. The essential difference between the two types lies in the direction of motion of the particles when compared with the direction of motion of the waves. Except that we substitute compression for crest and rarefaction for trough, the terms and definitions learned for transverse wave apply to longitudinal waves.

A *visible* train of longitudinal waves is *never* obtained in practice but the continuous operation is well illustrated by means of Crova's disc.

Crova's disc.—The disc should be of cardboard or thin sheet metal. On it a number of circles increasing in radii by small steps is drawn with centres 1, 2, 3, 4, etc. equally spaced around a small circle (Fig. 77). Suitable dimensions are: small circle, $\frac{1}{4}$ in. radius; circles with stepped radii, 1 in., $1\frac{1}{4}$ in., $1\frac{1}{2}$ in., etc.; diameter of card, 10 in. to 12 in. The disc, with a small hole bored concentrically with the small circle, is mounted on a turn-table. Independently, over it another sheet of cardboard with a rectangular slot cut in it is placed so that the arcs A, B, C, etc., of the circles are seen. This disc is rotated slowly so that the movement of each part A, B, etc., may be followed, and then more rapidly to show the compressions and rarefactions travelling along the slot.

The velocity of sound in air

Although sound travels rapidly in air, practically instantaneously in an ordinary sized room, its velocity is much less than that of light. The thunder-clap follows the flash of lightning at an interval depending on the distance of the storm, the marching of a long column of soldiers, keeping step to the music of the band which leads them, is distressingly irregular and the issue of "steam" from the sounding of a distant locomotive ceases before the sound which we hear.

Over distances of a few miles a direct determination of the velocity has been made by watching for the flash of a gun, fired at a pre-arranged moment, and waiting to time the arrival of the sound of the explosion. To obtain an accurate value by this method is a matter of difficulty, for winds and fluctuating temperatures affect the value which would be obtained in the ideal conditions of still air at a uniform temperature. In still air at a temperature of 0°C. sound travels with a velocity of 332 metres (or 1,092 ft.) per sec., and for every degree C. rise (or fall) of temperature the velocity increases (or decreases) by 61 cm. per sec. (or 2 ft. per sec.)

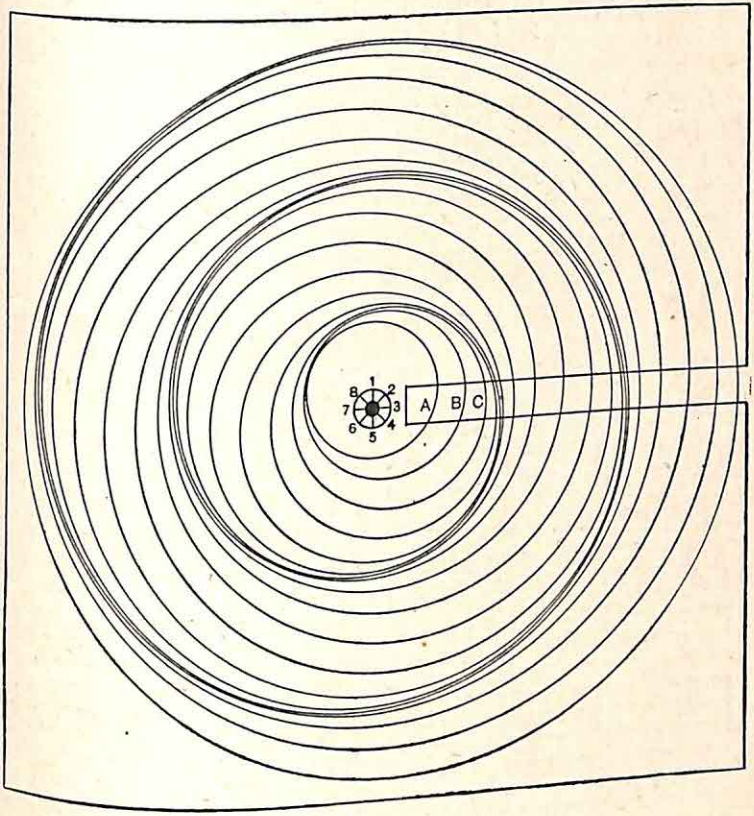

FIG. 77

Echoes

When sound waves from a source A reach a rigid wall or cliff MR (Fig. 78), they are reflected, and a listener at E would receive two sets of waves—one set directly from A and the other from an apparent source A′ (the sound image of A) behind the reflecting surface. If a sharply sounding source, such as the crack of a whip or a sudden shout, is used to obtain a very short wave train, and the source is 100 ft. or more from the wall, the listener at E, near the source, will receive the reflected waves as

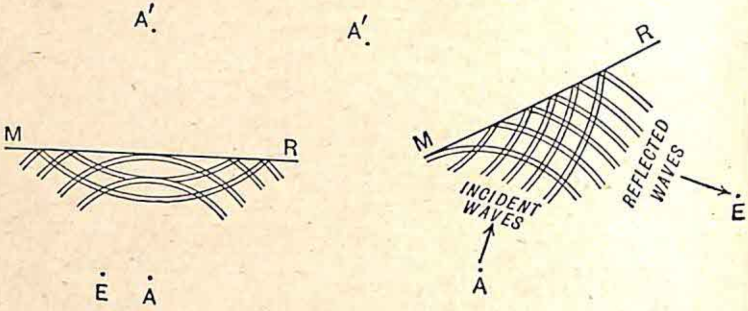

FIG. 78.

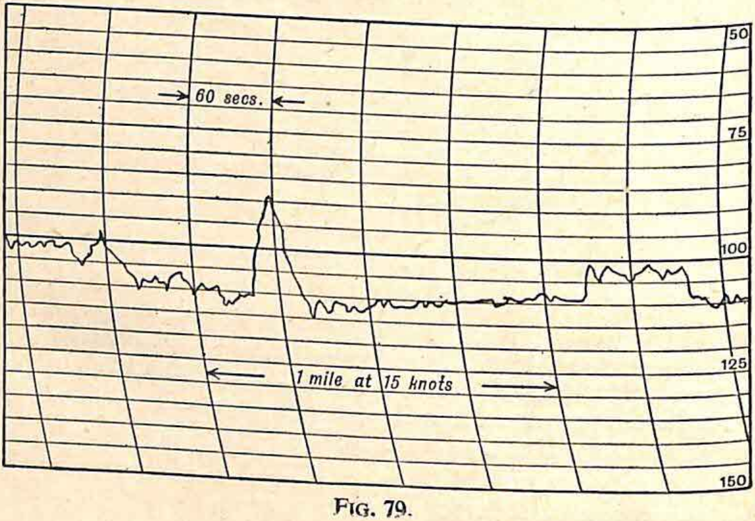

FIG. 79.

a separate set after the arrival of the waves transmitted directly. In these circumstances, two separate and similar sounds are heard; the second of these is the echo of the first.

Some echoes are produced for amusement, and others, of the nuisance type, occur in large public halls and long corridors. But one important use of echoes has been developed in recent years and, now, many large ships are equipped with a special form of recording apparatus from which sound waves are sent to the sea bed and after reflection are received as echoes. Sounds are dispatched every 2 seconds and the receipt of the echoes is plotted automatically on a revolving chart. Thus as the ship proceeds, it plots a contour of the sea bed beneath it and the old-fashioned "heaving of the lead" is unnecessary. Fig. 79 shows a section of a plot actually obtained in the Mediterranean; intervals between the curved lines are minutes and the depths are stated in fathoms.

Pitch and frequency

Our sense of hearing enables us to describe a musical note as high or low. This description of the note is called its pitch, but our ears do not tell us on what this pitch depends.

Expt. E.—A *long* thin blade of steel (the blade of a hack-saw will serve) is clamped at one end in a vice. The free end is displaced and released. The blade vibrates slowly enough for its movements to be seen and no sound is heard. The length of exposed blade is gradually shortened and the vibrations clearly increase in rapidity; also, at first a low humming note is heard and this gradually rises higher and higher as the successively shortened blade vibrates more rapidly. The pitch of the note clearly depends upon its frequency.

Since the frequency of sounds which affect the human ear covers a wide range (Book II, p. 153), a description of pitch as high or low is hardly sufficient, and it is usual to compare two or more sounds differing in pitch with the recognised sounds, doh, ray, me, fah, etc., of the musical scale. The relative frequencies of each of the principal notes of the scale, doh, me, soh, doh' are shown by the following experiment.

Expt. F.—A thin metal plate has small holes bored at equal distances on the circumferences of four concentric circles, the respective circles with increasing diameters having 24, 30, 36 and 48 holes. This disc, called a **disc siren**, is mounted on the axle of an electric motor connected, through a rheostat, to the mains (Fig. 80). When the motor is running steadily a draught of air from a wind chest is directed against the innermost circle of holes, and the periodic escape of air through hole after hole produces a note. Each of the other circles is treated in turn and the four notes heard are identified as doh, me, soh, doh$^{\text{l}}$. The rheostat is altered to change the speed of rotation and the test carried out as before. The notes heard are different, but as a group they form a similar sequence.

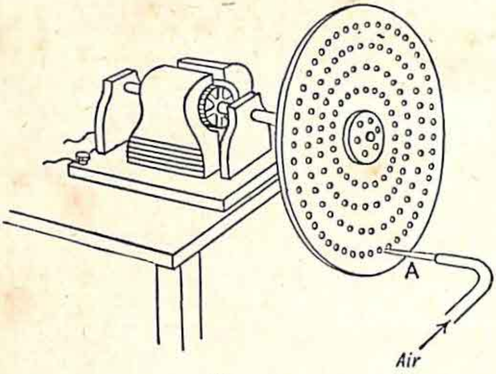

FIG. 80.

For a steady rotation of the disc, it is evident that the frequencies of compression produced by escaping air are in the ratio 24 : 30 : 36 : 48. Thus the frequencies of the principal notes of the scale are in the same ratio. With a siren having eight circles of 24, 27, 30, 32, 36, 40, 45 and 48 holes we should obtain all the notes of the common scale ; thus when we hear two notes which we can identify in the musical scale, we can at once state the ratio of their frequencies.

It should be noted that the rapidity of vibration of the source has no sensible effect upon the velocity of the sound waves propagated in the air. That this is true for notes of any pitch is shown by the simple test of listening to a band playing a familiar tune. No matter how far we may be from the band, the music sounds the same; it would not if the sounds of different pitch travelled from the instruments to our ears with different velocities.

The frequency of stretched strings

A violinist in tuning his instrument turns a peg to increase or decrease the tension of the faulty string; to play the instrument, he produces notes of different pitch by pressing in different places on the string which is being bowed. We shall now investigate the conditions which are applied in the use of the violin and other stringed instruments.

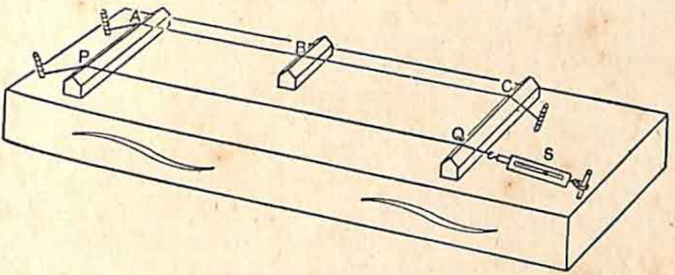

FIG. 81.

The apparatus to be used is a **sonometer** (Fig. 81). This consists of a strong box, acting as a sounding board, on which two thin steel strings are mounted over fixed bridges. The end of one string is attached to the hook of a spring-balance, the other end of which is fixed. Tension in the strings is varied by turning the mounting pegs with a key, and a movable bridge B is used to vary the length of string acting as the sounding source.

Expt. G.—How does the frequency depend upon the length of the string?

With the adjustable bridge removed, both strings are tuned to the same pitch. Call these notes, doh. The bridge is then inserted under the wire AC and moved until the longer segment sounds me, then soh, and finally doh^{1}. In each case the length of the vibrating segment is measured and tabulated with the name of the note and its relative frequency. The relation between length and frequency is clearly an inverse one, for halving the length of the string doubles its frequency. Test the ratios for the intermediate notes.

Note	Relative frequency	Length of wire
Doh	24	100 cm.
Me	30	—
Soh	36	—
Doh$^{\text{l}}$	48	—

What are the conditions of tension in the wire AC during this experiment ?

Expt. H.—How does frequency depend upon the tension ?

Both strings are tuned to the same pitch and the tension of PQ read on the spring-balance. Using the note of AC as doh, the spring PQ is then tightened until it sounds me, then soh, and finally doh$^{\text{l}}$; in each case the tension is read on the spring-balance and recorded with the note and its relative frequency. Here the frequency increases with the tension. Doubling the frequency requires a tension four times as great ; thus frequency varies as the square root of the tension. Test this relation for the intermediate notes of the scale. Note in this experiment the length of the vibrating string remains constant.

Note	Relative frequency	Tension
Doh	24	—
Me	30	—
Soh	—	—
Doh$^{\text{l}}$	—	—

Resonance

Although a stationary, heavy body, possessing great inertia, would show a marked tendency to remain at rest, it is possible to set it in *oscillation* and build up a large amplitude of swing by means of a relatively feeble force.

Expt. J.—A *heavy* iron ball is fitted up as a pendulum. To the side of the ball is attached a single fibre of unspun silk. With a steady pull on the fibre, it breaks before the ball is appreciably displaced. Another fibre is mounted, pulled feebly and released. This starts the pendulum swinging with a very small amplitude ; each time the ball swings towards the experimenter the fibre is given another feeble pull, and is again released. In this way a large amplitude is built up.

The production of this large amplitude depends entirely on the timing of the feeble force brought into action and the continued response of the oscillating body is known as **resonance.** A garden swing, operated by a small child, has its amplitude similarly built up by a succession of properly timed small forces.

The examples given are cases of mechanical resonance, and in certain circumstances danger may arise if precaution is not taken to avoid its occurrence. Every body has its own period of oscillation, and if small forces are applied to it at intervals coinciding with its own period, a dangerously large amplitude may be set up. A company of soldiers marching in step over a suspension bridge may have a frequency of tread which is the same as the frequency of oscillation of the bridge, in which case the bridge would respond more and more to the correctly timed steps and disaster might ensue. For this reason, the company is always ordered to break step when crossing the bridge.

Acoustic resonance

If two bodies have the same frequency and one is already vibrating, it will set the other in sympathetic vibration if suitably connected with it. Thus if the disc siren is adjusted to produce a frequency of (say) 256 vibrations per sec. and the prong of a tuning fork of the same frequency is held in the path of the escaping air, the successive compressions acting on the prong are exactly timed to increase its motion and its note is heard when the air supply is cut off. Resonance which sets up vibrations rapid enough to produce sounds is known as acoustic resonance, and it is usefully employed to set up large vibrations in columns of air and, as in organ pipes, cause them to resound loudly although the actuating source is one of feeble power.

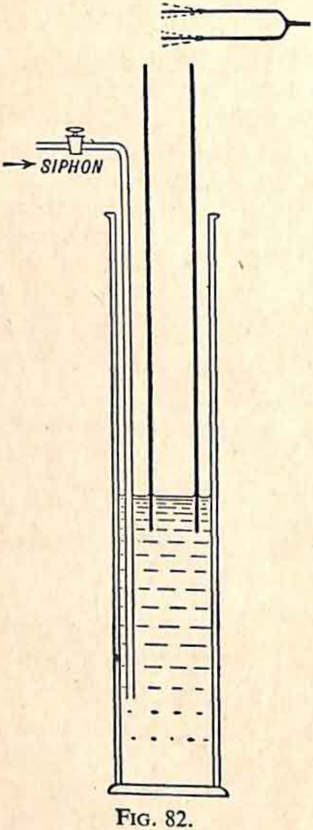

FIG. 82.

Expt. K.—A glass tube, diameter 2–3 cm. and length about 40 cm. is mounted in a tall glass cylinder partly filled with water (Fig. 82).

A tuning fork, frequency 256 per sec., is sounded and is inaudible except to those very near it. It is held over the mouth of the tube and still remains generally inaudible. With the fork vibrating over the mouth of the tube, water is quietly siphoned into the cylinder, and soon a sudden increase in the intensity of the sound is heard. At this stage, the siphon is stopped. Forks of frequency 320, 384 and 512 per sec. are now sounded in turn in place of the first one ; in each case no response is obtained until more water is siphoned in to produce a resounding column of air of the appropriate length for the frequency employed. Frequencies and lengths of resounding column should be tabulated and compared.

Since the lower end of each column of air used above is closed by the surface of the water, the response in these cases is classified as resonance in a closed tube. We shall now consider the response in an open tube.

The glass tube is removed from the water, dried and wound round with a few layers of stiff paper, held in position by rubber bands. The vibrating forks are held in turn over one end of the tube, and the correct resounding length obtained by sliding the paper cylinder partly over the end of the glass tube. Frequencies and lengths are again tabulated and compared. The test for the fork of frequency 512 per sec. fails. Why? Finally, compare the lengths of open and closed tube which resound to the same frequency.

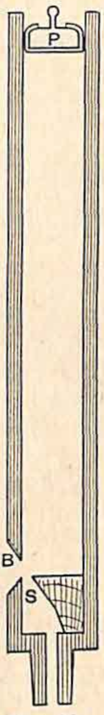

FIG. 83.

The air particles of any of these columns of air vibrate with a fixed frequency which depends upon the length of the pipe and whether it is closed or open. (Try blowing steadily across one end of a piece of glass tubing, opening and closing the remote end with the finger.) **Resonance occurs** when the vibrations of the particles are built up by the persistent impulses of a **sounding source which has the same frequency as that of the particles themselves.**

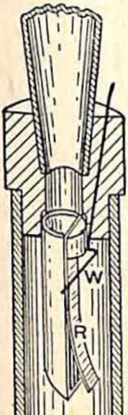

FIG. 84.

Organ pipes are of two kinds. In the *flue pipe* (Fig. 83) a steady stream of air from the bellows is directed through the slit S against the sharp edge of the blade B. The latter, in vibration under the slight pressure of the air, is the source which causes the air in the pipe to resound. The pipe may be left open at the top and act as an open pipe; alternately it may be closed at the top by a leather-covered plug P and act as a closed pipe. In the *reed pipe* (Fig. 84) the air column resounds to the vibration of a reed R, which is "tuned" to the required frequency by pushing down the wire W to adjust the length of reed actually set in vibration. The mounting of this reed virtually closes the lower end of the pipe which thus operates always as a closed pipe.

CHAPTER 11

IMAGES. OPTICAL INSTRUMENTS.

Behaviour of light rays (revision)

Light is a form of radiation emitted by a body at, or above, a temperature roughly described as red-hot ; it travels in straight lines, and each straight path is called a ray. When a beam of rays is incident upon the surface of a medium, the light may be (*a*) reflected, (*b*) transmitted, or (*c*) absorbed.

(*a*) **Reflection.**—If the surface is perfectly plane, the reflection is regular and corresponding angles of incidence and reflection are equal ; if the surface is uneven or unpolished, the reflection is diffuse. For a concave mirror rays diverging from its centre of curvature lie on normals and are reflected along their incident paths ; rays parallel and close to the principal axis are reflected through one point—the principal focus—midway between the centre of curvature and the pole of the mirror. Conversely, rays diverging from this focus are rendered parallel by reflection from the mirror.

(*b*) When **transmission** occurs, the direction of the ray is usually altered ; this is the process of refraction, which is always accompanied by partial reflection. For oblique incidence, light entering a denser medium has its speed reduced and turns towards the normal. Conversely, if light enters a rarer medium the speed is increased and rays are refracted away from the normal. But if the angle of incidence in the denser medium exceeds a certain value—the critical angle—transmission to the rarer medium ceases, and the incident light is totally internally reflected. No change in direction occurs during the transmission of rays incident normally to a refracting surface. A beam of rays parallel and close to the principal axis of a thin convex lens is refracted through one point—the principal focus—conversely, rays diverging from this focus are rendered parallel after passing through the lens. Any ray passing (not too obliquely) through the optic centre of the lens proceeds without perceptible change of direction.

(*c*) **Absorption.**—If absorption is complete, the object appears black ; if partial, then the light which is reflected or refracted, on reaching the retina of the eye, enables us to decide the colour of the object. If the incident light is white, the colour assigned is the natural colour of the object.

Images

If light from an object is reflected or refracted before reaching the eye and then focused sharply on the retina, an image of the object is viewed. These images are either (*a*) real or (*b*) virtual. Real images are formed by actual focusing of converging rays and are viewed by means of diverging rays passing from the image to the eye. Consequently all real images may be projected on a screen. To produce a real image by means of a concave mirror or a convex lens, the object must be placed, in either instance, at a distance exceeding the focal length of the mirror or lens used.

If after reflection or refraction, the rays diverge continuously until they reach the eye, the image on the retina gives effect to the appearance of a virtual image. This type of image may be produced by placing the object (1) at any distance from a plane mirror or a plane refracting surface, (2) between the principal focus and the pole of a concave mirror, and (3) between the optic centre and the principal focus of a convex lens. In all these instances light rays diverging from the object remain diverging after they have been reflected or refracted; they are rendered converging only by the eye lens which brings them to a focus on the retina.

The eye and the photographic camera

In dealing with the process of viewing an image we have relied almost entirely on the functions of the lens and the retina of the eye. These suffice to account for the production and focusing of the image. But there are other components of the eye (Book II, p. 151) which operate to produce suitable conditions for viewing the image clearly and comfortably. In extending our knowledge of the optical arrangements of the eye, we shall compare them with those of a camera ; the corresponding parts

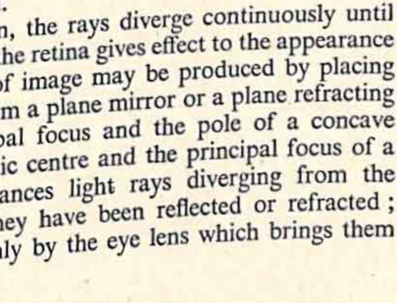

FIG. 85.—THE EYE.

are much alike in purpose and behaviour, though not in their methods of operation.

The lens of the eye has a focal length variable to a small extent; the focal length of a camera lens is usually fixed.[1] Each lens refracts the incident rays to form a real image sharply in focus on a screen: in the eye this is the retina; in the camera it is the sensitive plate. The plate, however, gives uniform response over its entire surface, while the retina forms the sharpest image in the region of the yellow spot.

The image distance in the eye is constant and accommodation is provided by varying the focal length of the lens by the action of the ciliary muscles and ligaments. In the camera, the lens is usually moved to adjust accurately the image distance[1] to correspond to the distance of the object. Just as the ciliary muscles do not usually accommodate the eye for objects nearer than 10 in., so the extent to which the camera lens may be moved outwards fixes the least distances of objects for which sharply defined images may be obtained on the plate.

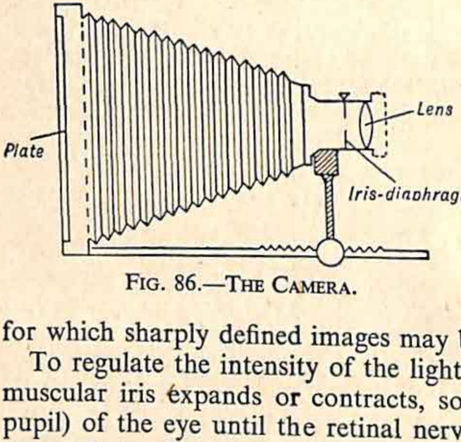

FIG. 86.—THE CAMERA.

To regulate the intensity of the light falling on the retina, the muscular iris expands or contracts, so varying the aperture (or pupil) of the eye until the retinal nerves are stimulated without discomfort. To regulate the entry of light, in accordance with the exposure he intends to allow, the photographer adjusts the iris diaphragm (or stop) of his camera. Complete exclusion of light from the eye is obtained by closing the eye-lid, and from a camera by closing the shutter.

Reflection of light by convex mirrors

Any polished or silvered surface of a solid sphere will serve as a convex mirror; if a portion of a spherical shell is used, the reflecting surface must face the outside. A cylindrical surface provides a special type of convex mirror, producing only in certain circumstances the same results as those obtained by using the spherical form of mirror.

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[1] Some cameras have a fixed image distance and the focal length of the compound lens is altered by screwing one component lens nearer to or farther from the adjacent one.

The terms *pole*, *centre of curvature and principal axis* are defined exactly as they were in the case of a concave mirror, but you will note that for a convex mirror the *centre of curvature is behind the reflecting surface.*

EXPT. 1.—*To study the reflection by a convex mirror of—*

(*a*) *A set of parallel incident rays.*
(*b*) *A set of incident rays diverging from a point.*

Apparatus: Light-beam apparatus (Bk. II, p. 285), triple slit, a comb, a cylindrical convex mirror.

(*a*) Assemble the apparatus for parallel rays (Fig. 87). Place the mirror across these rays so that they are reflected in turn by different parts of it. What happens to the reflected rays in each position tested? Adjust the mirror so that the central incident ray lies on the principal axis of the mirror and is consequently reflected back along its path. Mark the pole of the mirror and **draw accurately** the paths of the incident and reflected rays and the line MR on which the mirror stands. Produce the lines of the reflected rays backwards behind the mirror line. They meet at a point.

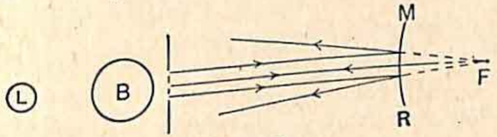


FIG. 87.

Repeat the experiment, substituting a comb for a triple slit and verify that the previous observation only applies if the rays are reflected from positions near the pole of the mirror.

When reflected by a convex mirror, rays parallel and close to the principal axis are not brought to a focus; they diverge as if coming from a point behind the reflecting surface. This point is the **principal focus** of the mirror, and its distance from the pole is the focal length. Since no light arrives at, or proceeds from, F, the principal focus of a convex mirror is a **virtual focus.**

(*b*) Arrange the apparatus (Fig. 88) to produce a set of rays diverging from S. Place the mirror across these rays as far as possible from S, and gradually move it towards this point. Observe the reflected rays for a number of positions of the mirror, and verify occasionally that the paths of these rays, produced backwards, meet at a point beyond the reflecting surface.

These reflected rays are never brought to a real focus ; they always diverge from a virtual focus I behind the mirror. I is the image of S and so it is evident that when light from a point source, or a group of point sources, is reflected by a convex mirror, the image formed must always be virtual in character.

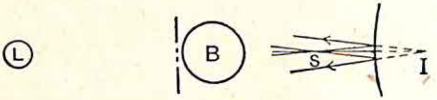


FIG. 88.

EXPT. 2.—*Is there any relationship between the focal length and the radius of curvature of a convex mirror?*

Apparatus : Light-beam apparatus, triple slit, convex mirror, cylindrical convex lens, centimetre scale.

Note.—The centre of curvature lies behind a convex mirror.

First, as in Expt. 1 (*a*), determine the focal length of the mirror. Then arrange the apparatus to provide a set of diverging rays and place the convex lens across these (Fig. 89) to obtain, fairly distant from the lens, a focus C of the refracted rays. Place the mirror across these rays and adjust its position so that they are reflected along their paths, through the lens to S. Then each ray from the lens to the mirror lies on a normal to the latter and, if continued beyond the mirror, would pass through its centre, i.e. through C. Trace the mirror, remove it, mark the point C and measure the radius of curvature. Compare the radius with the focal length.

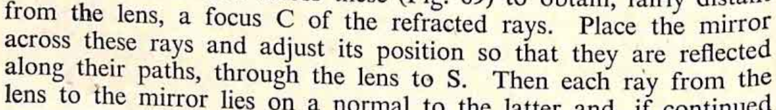


FIG. 89.

Readjust the mirror so that the reflected rays are parallel and then deduce the focal length of the mirror.

Summarise the results of these experiments to state how the following incident rays are reflected from a convex mirror ; thus :

(1) Rays parallel to the principal axis are reflected. . . .
(2) Rays directed towards the centre of curvature are reflected. . . .
(3) Rays directed towards the principal focus are. . . .

Graphical construction for image

As the above rules apply only for rays striking the mirror near its pole, we shall use a *reference line*, as previously, to determine the directions of the reflected rays.

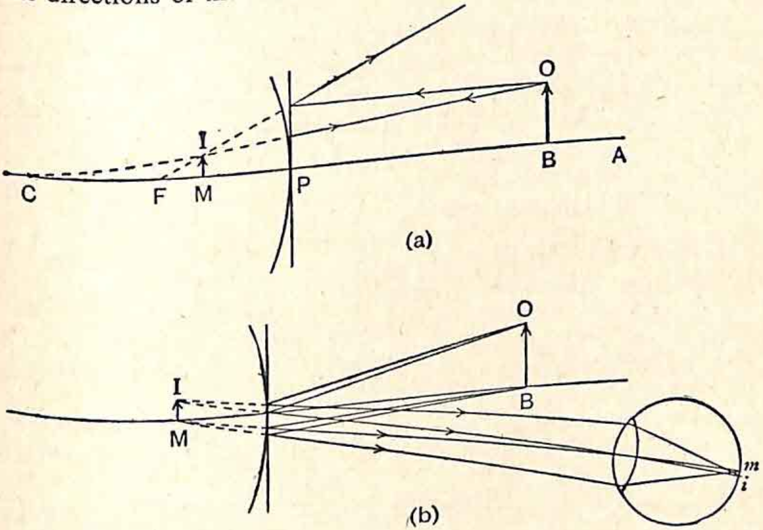


FIG. 90.

In Fig. 90 (*a*), PA is the principal axis of a convex mirror, P its pole and C its centre. The virtual principal focus lies midway between P and C. OB is the object, placed for convenience with B on the axis (Book II, p. 261). A ray from O parallel to PA is reflected as if coming from F, and another from O directed towards C is reflected along its incident path. These rays (and others) will diverge as if coming from I, the image of O. Similarly all points below O have images in corresponding order below I; hence IM is the complete image of OB. Fig. 90 (*b*) illustrates the process of viewing this image.

However often this construction is repeated for different distances of the object from the mirror, four features of the image remain unchanged; it is always (1) virtual, (2) erect, (3) situated between the principal focus and the pole, and (4) smaller in size than the object. Because of these features, the convex mirror is specially suitable as an *external* driving mirror for a motor vehicle.

Refraction by a concave lens

A concave lens is a refracting medium, usually of glass, whose surfaces are (1) both spherical, or (2) one spherical and one plane. It is thinner in the middle than round the edge. The lens as a whole has no centre of curvature and its principal axis is defined as for a convex lens (Book II, p. 251). Cylindrical concave lenses have the same experimental advantages and practical limitations as cylindrical convex lenses.

EXPT. 3.—*To study the refraction by a concave lens of—*

(*a*) *A set of parallel incident rays.*

(*b*) *A set of rays diverging from a point source.*

Apparatus: Light-beam apparatus, triple slit, a comb, a cylindrical concave lens, centimetre scale.

(*a*) Assemble the apparatus for parallel rays (Fig. 91), placing the lens across these so that as a group they traverse different parts of the lens. In each case the rays diverge after leaving the lens. Now arrange the lens so that its principal axis and the central ray are coincident, and trace the lens and rays accurately to find the point F from which the divergent rays appear to come. This is the principal focus of the lens (clearly, a virtual focus) and its distance from the lens is the focal length. Measure and record its value.

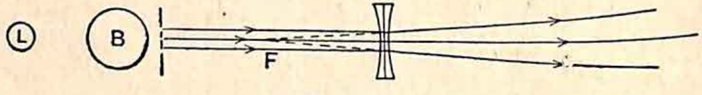


FIG. 91.

Substitute the comb for the triple slit and verify that statements about the principal focus apply only to rays passing through the lens near its centre.

(*b*) Rearrange the apparatus as in Fig. 92. Start with the lens across the diverging rays as far as possible from the source S, and gradually move it towards S, observing the rays after refraction for several positions of the lens.

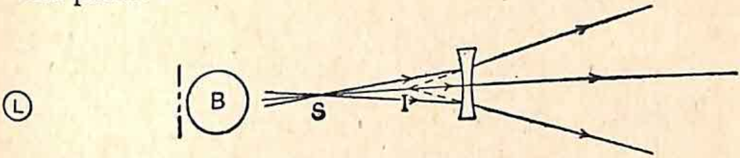


FIG. 92.

The refracted rays are never brought to a real focus; they always diverge from a virtual focus I, on the same side of the lens as S. I is the image of S; hence it is evident that when rays diverging from a point source, or a group of point sources, are refracted by a concave lens, the image produced must always be virtual in character.

The optic centre of a concave lens

This point has the same property as the optic centre of a convex lens. This may readily be verified by assembling the light-beam apparatus as in Fig. 93. The procedure is exactly the same as that adopted when dealing with a convex lens (Book II, p. 252).

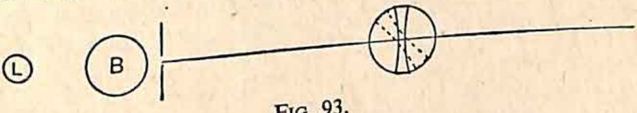


FIG. 93.

Graphical construction for image

Fig. 94 (*a*) illustrates how the properties of rays are used to determine the position of the image which is shown at IM. The diagram takes the same form whatever the distance, CB, of the object from the lens, so that we may state that the image is always (1) erect, (2) virtual, (3) situated between the optic centre and the principal focus, and (4) smaller than the object. The accompanying diagram, Fig. 94 (*b*), shows how this image is viewed by the eye.

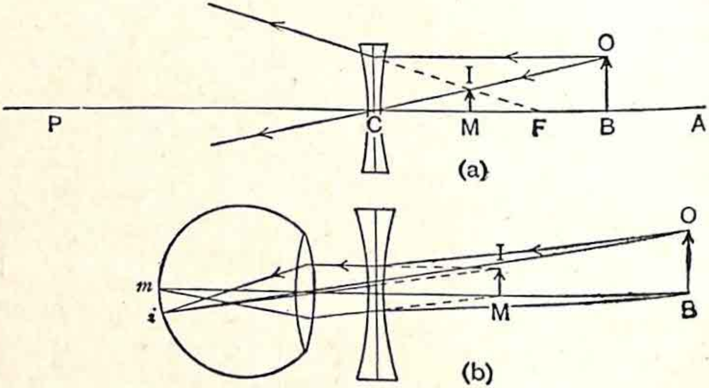
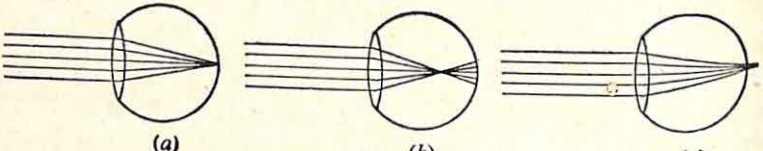


FIG. 94.

Defective sight

When the ciliary muscles of a normal eye are relaxed, the lens, then at its thinnest, is shaped to focus a beam of incident parallel rays on the retina (Fig. 95*a*). In these circumstances we say the eye is **at rest**, and this special case of vision is described as viewing an object at infinity. The pupil of the eye is so small that rays from any point lying more than 20 feet away enter the lens in directions which are sensibly parallel; consequently, in practice, all such points are considered to be "at infinity."



(*a*) (*b*) (*c*)

FIG. 95.

Now, all eyes are not normal. In some instances the eye-ball is too long, the focus of parallel rays lies in front of the retina (Fig. 95*b*), and the owner suffers from a defect known as short-sight; in others, the eye-ball is too short, the focus of parallel rays would lie behind the retina (Fig. 95*c*), and the owner suffers from long-sight. In either case, *with the eye at rest*, the rays would arrive on the retina slightly out of focus, and the visual result would be a blurred impression of the object viewed.

Short-sight

In this defect the focal length of the eye lens *at rest* should be longer (Fig. 95*b*), and there is nothing which the ciliary muscles can do to secure this need. But as the object at infinity is brought nearer, the image will gradually move away from the principal focus and ultimately lie on the retina. At this stage, the object is in a position called the **far-point of the eye** ; nearer than this position, the object comes within the range for which accommodation is provided by the ciliary muscles, and clear, unassisted vision is possible. From objects beyond the far-point, the rays which would be focused in front of the retina are first made to diverge slightly by passing them through a **concave lens.** This lens is chosen so that, in the case of parallel rays, the new divergence is directed from the far-point (Fig. 96) ; the image is then obtained on the retina.

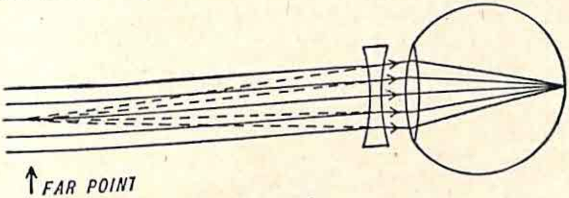


FIG. 96.

Long-sight

In this case, the shortness of the eye-ball does not necessarily cause a blurred retinal image of a distant object, for the ciliary muscles can be exercised to shorten the focal length of the lens. This simply means that a distant object is not viewed by a long-sighted eye at rest. As the object is moved towards the eye, the accommodation of the ciliary muscles reaches its limit, and when this occurs the object is situated at the **near-point of the eye,** which will usually be further away than 25 cm. Rays from objects less distant than the near-point (Fig. 97) would be focused behind the retina; to obtain the focus on the retina a convex lens is used to make the rays less divergent before entering the eye. This lens is chosen so that when the object is 25 cm. from the eye, rays enter the eye as if coming from the near-point.

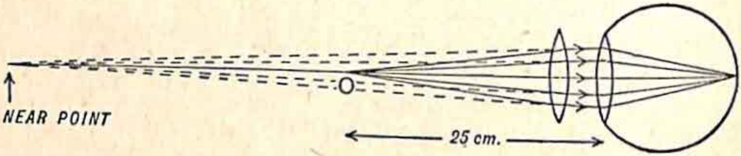


FIG. 97.

Aids to vision

The real image on the retina (Fig. 98) is always smaller and often very much smaller than the object viewed. Consequently, when observing a distant object, or even a small object at 25 cm. distance, the normal eye is often incapable of detecting the details. In such disadvantageous circumstances, the observer must assist his vision by using a telescope or a microscope. Observation through these optical instruments constitutes the most important use of images; in either case, light rays from the object must pass through the instrument which is used, and so detailed information is obtained by the examination of an image and not of the object itself.

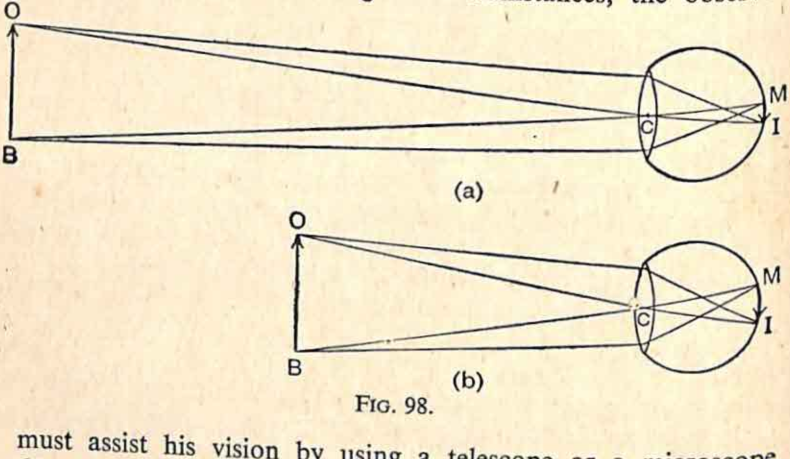


FIG. 98.

The angle of vision

Consideration of the retinal images in Fig. 98 shows that as the image of a particular object increases in size, the angle ICM which the image subtends at the optic centre of the eye also increases. Since rays pass undeviated through the optic centre, it follows that the angle ICM is equal to the angle OCB, the angle subtended at the optic centre by the object. This angle OCB is known as the angle of vision; clearly, if it is not large enough, the image will be too small for its details to be visible.

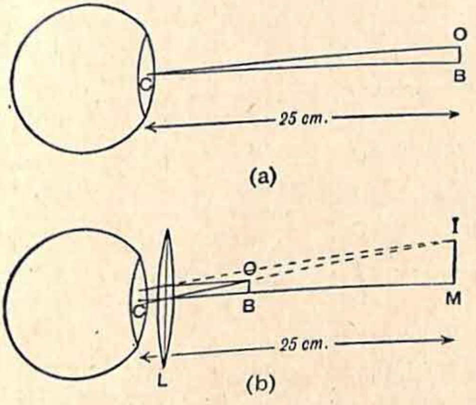


FIG. 99.

When this is so, an image with a larger angle of vision must first be formed outside the eye; the corresponding image on the retina is then large enough to show the necessary detail. This is the essential purpose of all optical instruments and is clearly shown in the case of the **simple microscope** or **magnifying glass**. For a small object at 25 cm., Fig. 99 (*a*), the angle OCB is too small; at the shorter distance, Fig. 99 (*b*), the angle of vision has been increased, but now OB lies well within the least distance of distinct vision. A convex lens L is therefore interposed to form a virtual image at 25 cm. (Book II, p. 267). This image is distinctly visible and its angle of vision is practically the same as that of the object.

The compound microscope

For very small objects, e.g. amœba, the magnification obtainable with a simple microscope is insufficient to reveal details. In such instances, a convex lens, called the **objective** (Fig. 100) is used to produce a magnified real image IM of the very small object OB; this real image is situated near to the eye to secure a large angle of vision, and a second convex lens, called the **eyepiece**, is interposed to form a final virtual image I_1M_1. This arrangement of convex lenses is the compound microscope. When using the compound microscope, it is usual to view the final image situated at the near-point, i.e. 25 cm. from a normal eye.

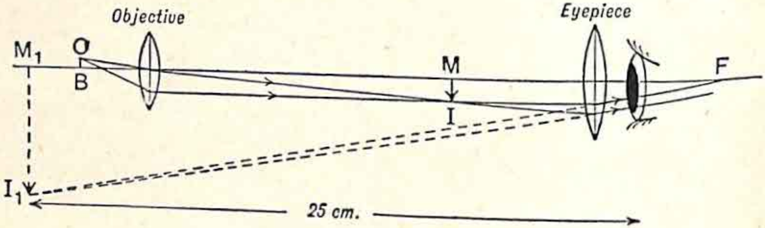


FIG. 100.

Since IM is a real and much magnified image, the distance from the object OB to the objective must just exceed the focal length of the latter. Clearly also, for high magnification the image IM is relatively much further than the object from the objective. Consequently to keep the length of the instrument within convenient limits, the focal length of the objective must be very short, e.g. 1 cm. The eyepiece acts as a simple microscope used to view IM, and although its focal length is usually longer than that of the objective, it must be short enough to give good magnification of the real image.

The astronomical telescope

This instrument is used for objects far enough away to be considered at infinity. It consists of a **convex objective** and a **convex eyepiece**, but their selection and arrangement differ from that of a compound microscope because of the great distance between the object and the objective.

Rays from any point on the object reach the telescope as a parallel beam (Fig. 101); consequently the real image IM formed by the objective is situated at the principal focus of this lens. The eye is placed near this image to obtain a conveniently large angle of vision and the eyepiece is then interposed to obtain a final magnified virtual image. Usually, the eye chooses to view this image at the far-point, i.e. it remains at rest and so it must receive beams of parallel rays from the eyepiece.

For the eye to receive parallel rays, the image IM must be at the principal focus of the eyepiece. Further, if the image IM is to be near the eye, it follows that the **focal length of the eyepiece must be short.** Consider again that this image is also situated at the principal focus of the objective. Examination of the rays through the optic centre shows that the further the image is from the objective, the greater is its size and correspondingly the greater the angle of vision subtended by it at the eye. Consequently the **focal length of the objective should be as long as is conveniently possible.** Lastly, the length of the telescope is the sum of the focal lengths of the lenses used; clearly this result affects the choice of the lenses, particularly the objective.

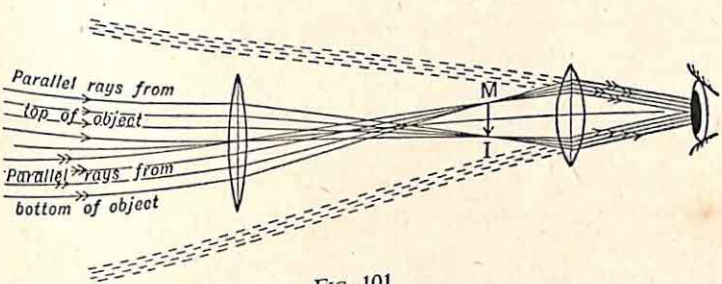


FIG. 101.

It should be noted that the final virtual image is an inverted copy of the object, for which reason this telescope is of little use for terrestrial purposes. It is, however, suitable for astronomical work—hence its name—and it was for such work that Galileo used the instrument (Book II, p. 220).

Galileo is credited with the invention of a second telescope —the Galileo telescope– in which he used a concave eyepiece to produce an erect final image and so made an instrument suitable for terrestrial work.

EXPT. 4.—*To study the effect of placing a concave lens across a beam of rays converging to a point.*

Apparatus : Light-beam apparatus, triple slit, cylindrical convex and concave lenses, centimetre scale.

First, as in Expt. 3 (*a*), determine the focal length of the concave lens. Then, arrange the lamp and triple slit for a set of diverging rays and place the convex lens across these (Fig. 102), so that the refracted rays converge to a *fairly distant* focus F. Now place the concave lens across these *converging* rays so as to make them diverge and then move it gradually from the convex lens towards F. The divergence becomes less and finally the rays are parallel. At this stage, trace in the concave lens and remove it. Mark the point F, and determine its distance from the marked position of the concave lens.

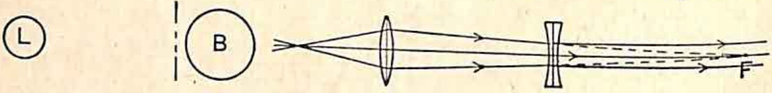


FIG. 102.

This distance agrees with that obtained for the focal length. Clearly then, rays which converge towards the principal focus lying beyond a concave lens are refracted by that lens as a parallel beam. This is the property of a concave lens which is applied in using a concave eyepiece in the Galileo telescope.

The Galileo telescope

A **convex objective** (Fig. 103) of long focal length receives parallel rays from a distant object and so *would form* a real image IM at the principal focus of this lens. Before the converging rays reach their focus, they pass through the **concave eyepiece** which renders them parallel. Then, entering the eye at rest, they are brought to a focus on the retina and enable the observer to view a final virtual and erect image at the far-point. To obtain parallel rays from the eyepiece, it must be placed at a distance equal to its focal length from IM and on the same side of IM as the objective.

The length of this telescope is equal to the difference of the focal lengths of the lenses used. This appears to provide an additional advantage, because this length is shorter than that of the corresponding astronomical telescope which would obtain the same magnification. Unfortunately, for practical reasons, the Galileo telescope cannot be made to obtain high magnification. But where small magnification suffices and compactness of design is desirable, as in the use of opera glasses and field glasses, this instrument possesses a two-fold advantage over the astronomical telescope—it is easily manipulated and its final image is erect.

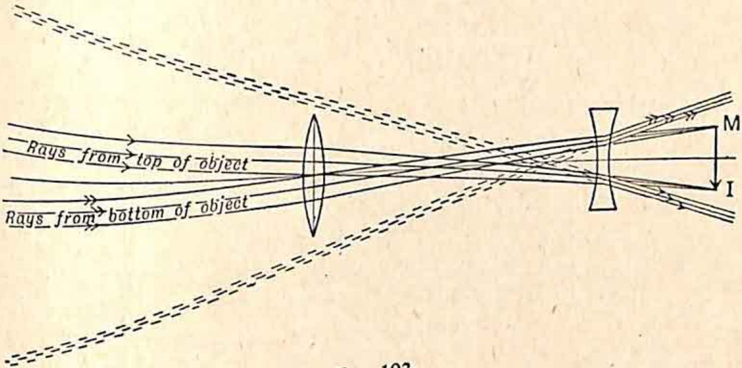


FIG. 103.

CHAPTER 12

PRESSURE IN FLUIDS

Force and pressure

When used in a general sense, the terms force and pressure usually denote the same thing—the action of one substance pressing upon another. In scientific language, and especially when we express the strength of a force or a pressure by means of a numerical value, the two terms have definite and distinctive meanings. To make clear the difference between force and pressure, we shall consider some simple cases.

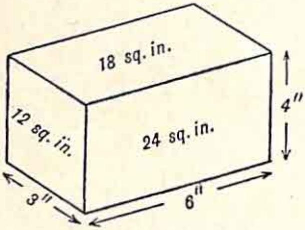


FIG. 104.

(*a*) Consider a rectangular block of wood, say 6 in. × 4 in. × 3 in. and weighing 30 oz. (Fig. 104), lying on a horizontal plane. Irrespective of the face which makes contact with the bench, the block is pressing on the bench with a force of 30 oz. But when we consider which face makes contact, then it is evident that this force of 30 oz. may be distributed over 24 sq. in., over 18 sq. in. or over 12 sq. in. of bench surface. The **distribution of the force** is stated by calculating how much of it acts on each unit of area. This is making a statement of the **pressure**, which is then defined as force per unit area. In the example given, its value would be stated in oz. per sq. in.; other units are lb. per sq. in., lb. per sq. ft., and grm. per sq. cm.

(*b*) Since pressure$=\frac{\text{force}}{\text{area}}$, it is evident that a *small force* will produce a *large pressure* if the area on which the force acts is sufficiently small. Operated by the same force, a sharp blade cuts more easily than a blunt one. Conversely small pressures result from the application of forces over relatively large areas, e.g. in skiing, the weight of a man is distributed over the area of long skis (attached to the soles of his boots) and the small pressure so produced makes little impression on the snow.

(*c*) When dealing with liquids it is more usual to speak of the force exerted by the liquid as the **thrust** of the liquid (*cf. the upthrust mentioned in Archimedes' principle, Book I, p.* 17).

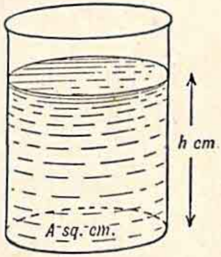


FIG. 105.

Consider a cylinder (Fig. 105) of cross-section A sq. cm. containing a liquid of density d grm. per c.c. Suppose the depth of the liquid to be h cm., then its volume is hA c.c. and its weight, hAd grm. The liquid exerts a thrust of hAd grm. on the base of the cylinder, and this thrust is distributed over an area of A sq. cm.

Hence, the **pressure on the base of the cylinder**

$$=\frac{\text{thrust}}{\text{area}}=\frac{h.\text{A}.d.\text{grm.}}{\text{A sq. cm.}}=h.d \text{ grm. per sq. cm.}$$

The same value is obtained if the liquid is in a vessel of any shape of cross-section.

This result is important because it shows that the pressure of a column of liquid does not depend on the sectional area of the column.

Pressure in liquids

Expt. A.—To study the pressure at several points on the same level within a liquid.

Apparatus : Several lengths of glass tubing (6 mm.), bent and mounted, as shown, through corks fixed in a strip of ply-wood (Fig. 106), glass tank containing water, pipette, beaker containing paraffin oil.

The tubes are carefully pushed through their supporting corks so that their lower ends are on the same level, and oil is released from the pipette into each tube until the water is forced out and the oil just reaches the immersed ends of the tubes. The shape of the oil surface at these ends shows the different directions in

CHAPTER 12

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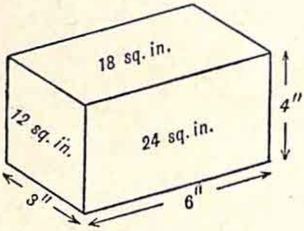


FIG. 104.

(*a*) Consider a rectangular block of wood, say 6 in. × 4 in. × 3 in. and weighing 30 oz. (Fig. 104), lying on a horizontal plane. Irrespective of the face which makes contact with the bench, the block is pressing on the bench with a force of 30 oz. But when we consider which face makes contact, then it is evident that this force of 30 oz. may be distributed over 24 sq. in., over 18 sq. in. or over 12 sq. in. of bench surface. The **distribution of the force** is stated by calculating how much of it acts on each unit of area. This is making a statement of the **pressure**, which is then defined as force per unit area. In the example given, its value would be stated in oz. per sq. in.; other units are lb. per sq. in., lb. per sq. ft., and grm. per sq. cm.

(*b*) Since $\text{pressure} = \frac{\text{force}}{\text{area}}$, it is evident that a *small force* will produce a *large pressure* if the area on which the force acts is sufficiently small. Operated by the same force, a sharp blade cuts more easily than a blunt one. Conversely small pressures result from the application of forces over relatively large areas, e.g. in skiing, the weight of a man is distributed over the area of long skis (attached to the soles of his boots) and the small pressure so produced makes little impression on the snow.

(*c*) When dealing with liquids it is more usual to speak of the force exerted by the liquid as the **thrust** of the liquid (*cf. the upthrust mentioned in Archimedes' principle, Book I, p.* 17).

Consider a cylinder (Fig. 105) of cross-section A sq. cm. containing a liquid of density *d* grm. per c.c. Suppose the depth of the liquid to be *h* cm., then its volume is *h*A c.c. and its weight, *h*A*d* grm. The liquid exerts a thrust of *h*A*d* grm. on the base of the cylinder, and this thrust is distributed over an area of A sq. cm.

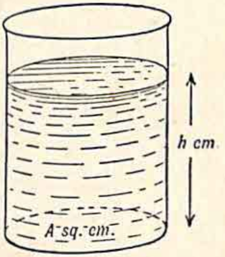


FIG. 105.

Hence, the **pressure on the base of the cylinder**

$$=\frac{\text{thrust}}{\text{area}}=\frac{h.\text{A}.d.\,\text{grm.}}{\text{A sq. cm.}}=h.d\ \text{grm. per sq. cm.}$$

The same value is obtained if the liquid is in a vessel of any shape of cross-section.

This result is important because it shows that the pressure of a column of liquid does not depend on the sectional area of the column.

Pressure in liquids

Expt. A.—To study the pressure at several points on the same level within a liquid.

Apparatus : Several lengths of glass tubing (6 mm.), bent and mounted, as shown, through corks fixed in a strip of ply-wood (Fig. 106), glass tank containing water, pipette, beaker containing paraffin oil.

The tubes are carefully pushed through their supporting corks so that their lower ends are on the same level, and oil is released from the pipette into each tube until the water is forced out and the oil just reaches the immersed ends of the tubes. The shape of the oil surface at these ends shows the different directions in which pressure is being exerted by the water. Further, the **heights** of the oil columns above the selected level are equal.

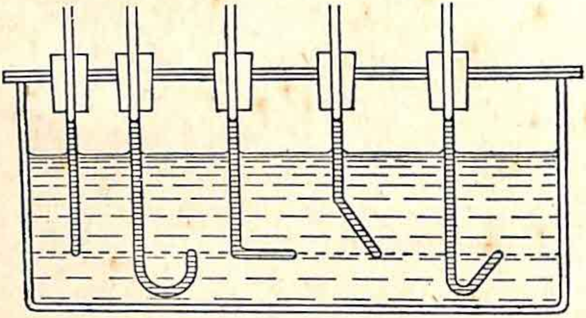


Fig. 106.

The tubes are now adjusted so that their immersed ends are on a different common level and the experiment is repeated.

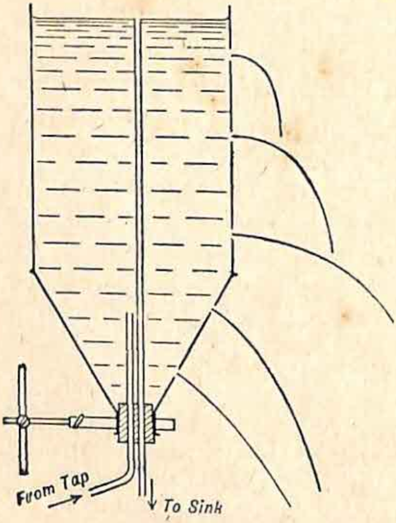


Fig. 107.

We may now conclude that **at all points on the same level within a liquid pressure is exerted equally in all directions.**

Expt. B.—What is the effective direction of pressure against the walls of a vessel containing a liquid?

The apparatus consists of a constant-level reservoir (Book II, p. 48) made from an old steam kettle with its base cut off. Small holes are drilled vertically beneath each other in the cylindrical side and in the conical surface of this reservoir (Fig. 107). Only inlet and outlet pipes are required, and the latter should reach nearly to the top of the vessel.

The water supply is adjusted to maintain a constant level at the top of the overflow pipe and the direction of each jet of water is observed just as it issues from the reservoir. This direction indicates the *effective direction* of the pressure, and is everywhere perpendicular to the wall of the reservoir.

Expt. C.—Without mechanical assistance, water from a reservoir cannot be forced to a height above that of the water level in the reservoir.

The reservoir is an aspirator with two side openings at the same level; through these openings two bent glass tubes are mounted by means of tightly fitting rubber stoppers (Fig. 108). The tubes are of different bore, and reach higher than the top of the aspirator.

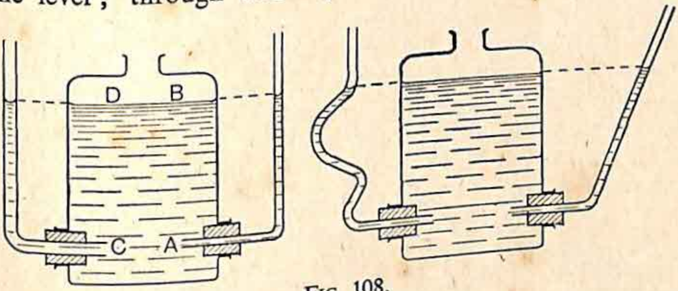


FIG. 108.

Water is poured into the reservoir and some of it passes into the tubes. When it is steady, the surface levels of the water in the reservoir and the tubes are the same. The tubes may be exchanged for others of different shape and bore, but the final result is unaltered.

"Water finds its own level"

Consider the result as shown in Fig. 108. There is a far greater weight of water in the reservoir than in either of the tubes, but this weight cannot force water in either tube to a level higher than that in the reservoir. Now, whatever the weight of water in either of these columns, *provided they are equal in height*, the pressure exerted by each is the same; within the reservoir, the pressures at C and A, on the same level, are equal and these pressures oppose those due to the water in the respective tubes. Since the water is at rest, these opposing pressures must be equal. **The height to which the column rises is therefore governed by conditions of pressure within the reservoir and not by the weight of water in it.**

Applications of the expression, pressure = height × density

Value of atmospheric pressure

It is usual to state the pressure of the air in terms of the height of the mercury column in the barometer (Book I, p. 145). We can now convert a pressure expressed in inches (or cm.) of mercury to the corresponding value in lb. per sq. in. (or grm. per sq. cm.) by multiplying the height of the column by the density of mercury. *Care must be taken to see that the units of height and density correspond.* Thus, if the height is 30 in., the density must be stated in lb. per cu. in. For mercury the value is 0·49 lb. per cu. in.

Hence the pressure = height × density

$$= 30 \times 0{\cdot}49 = 14{\cdot}7 \text{ lb. per sq. in.}$$

Determination of the density of a liquid

If we can arrange for columns of different liquids to balance each other, the pressures of these columns must be equal, and we may use this equality to determine the density of one liquid if we know that of the other. The experimental procedure differs according as the liquids will or will not mix with each other.

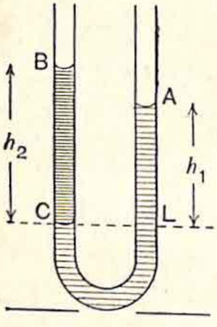


FIG. 109.

Case 1. For liquids which will not mix with each other

EXPT. 1.—*To use the U-tube to determine the density of paraffin.*

Apparatus: U-tube, stand and clamp, two small beakers containing respectively water and paraffin, centimetre scale.

Support the U-tube vertically by means of the clamp, and pour water into it until the limbs are about half-full. Pour a little paraffin into one limb and, when the liquids are steady (Fig. 109), measure the heights of surfaces A and B and of the common level [1] CL from the bench.

Above this level we have a column of water AL *balanced* by a column of oil BC. The pressures (height × density) of these columns are equal. Calculate the heights of these balancing columns. Enter the results as shown in the table and taking the density of water as 1 grm. per c.c., calculate the density of the oil. Add more oil in stages; repeat the readings and calculations to obtain several values for the density.

Finally calculate the average value of the density of paraffin.

Height of water column $= h_1$	Height of paraffin column $= h_2$	Density of paraffin $= \frac{h_1}{h_2} \times 1$ grm. per c.c.

Case 2. For liquids which will mix with each other

EXPT. 2.—*To use Hare's apparatus to determine the density of brine.*

Hare's apparatus is an inverted U-tube, with a short suction pipe A (Fig. 110) attached to the bend, and its open ends immersed in the respective liquids. The suction pipe is fitted with a short piece of rubber tubing which may be closed with a clip.

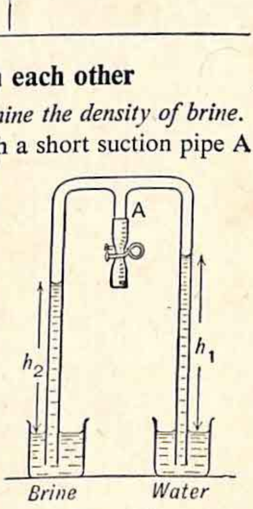


FIG. 110.

Apparatus: Hare's apparatus, stand and clamp, two small beakers containing respectively brine and water, centimetre scale.

Support the apparatus with the ends of the limbs well below the level of liquid in each beaker (Fig. 110). Open the clip and apply suction at A; close the clip when one of the limbs is nearly full.

The pressure of the atmosphere *on the liquid* in either beaker supports the column of liquid and the pressure of the enclosed air above the column. As the latter pressure is the same above both columns, it follows that the pressures of the respective liquid columns are equal.

---

[1] The horizontal line lying in the surface where the two liquids meet.

Obtain the lengths of the balancing columns, record them in a table as shown and then calculate the density of brine. Allow a little air to enter at A, and repeat the procedure to obtain more values for the density. Finally calculate the average of these values.

Height of water column $= h_1$	Height of brine column $= h_2$	Density of brine $= \frac{h_1}{h_2} \times 1$ grm. per c.c.

Measurement of gas pressure

In this case, the U-tube is used to obtain equality of pressure of a column of liquid and the gas. In these circumstances, the tube and its contained liquid act as a simple pressure gauge or manometer.

Normally the manometer liquid will find its own level in each limb ; when the gas pressure is applied this equality of level is disturbed (Fig. 111), and the pressure of the gas on the surface at C has raised a column of liquid AL against the pressure of the atmosphere. The pressure of the gas supply is therefore obtained by adding the pressure of the column of liquid to that of the atmosphere. For a normal gas supply, the manometer liquid would be water.

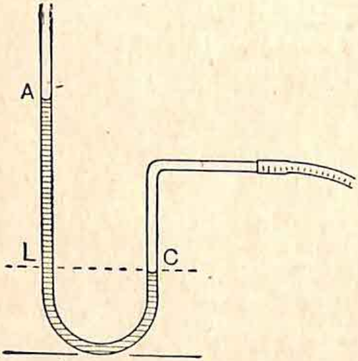
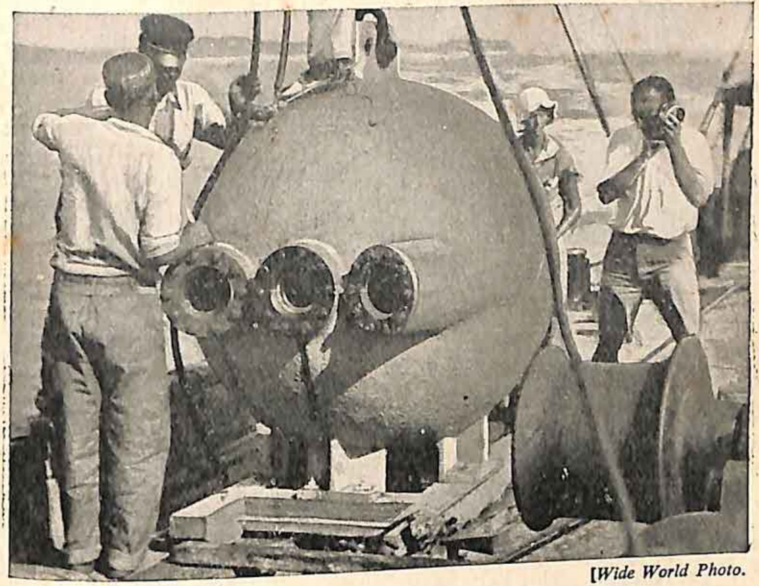


FIG. 111.

EXPT. 3.—*To determine the pressure of the gas supply in the laboratory.*

Apparatus : Manometer containing water, clamp and stand, length of rubber tubing, centimetre scale.



[*Wide World Photo.*

DR. WM. BEEBE AND HIS BATHYSPHERE.

Support the manometer in the clamp, and connect the horizontal arm to the gas tap with the rubber tubing. Turn the tap *slowly* up to full and, when the water is steady, obtain the height of the column AL supported by the gas pressure (Fig. 111). Read the height of the barometer. Record these readings and your answers to the following questions :

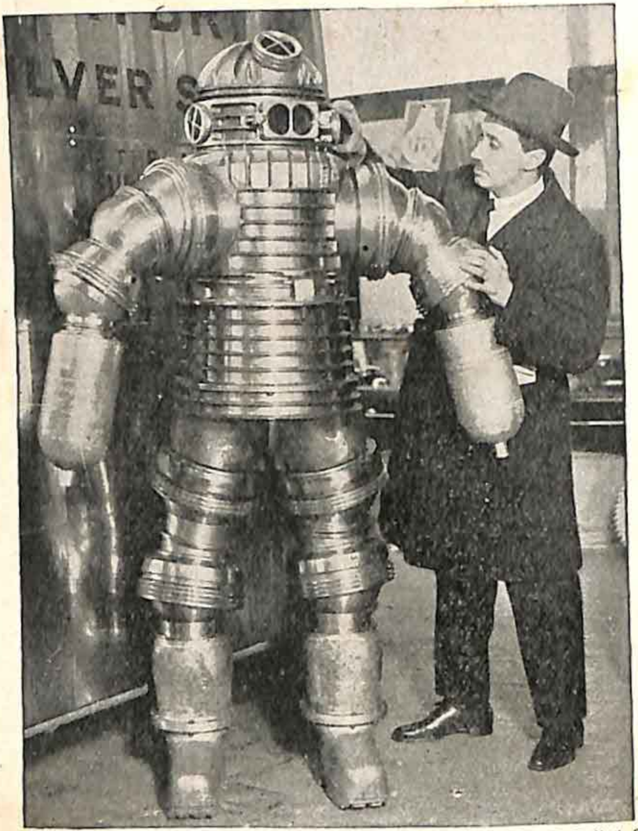
(*a*) What is the pressure in grams per sq. cm. of the water column AL ?

(*b*) What is the pressure in grams per sq. cm. of the atmosphere ? (density of mercury=13·6 grm. per c.c.).

(*c*) What is the total pressure of the gas ?

Deep-sea diving

The pressure on any surface *in* the sea is the sum of that due to the atmosphere (about 14·7 lb. per sq. in.) and that due to the sea water above the selected surface. As the pressure at great depths is large, it is more usually expressed in " atmospheres " than in lb. per sq. in. The average density of sea

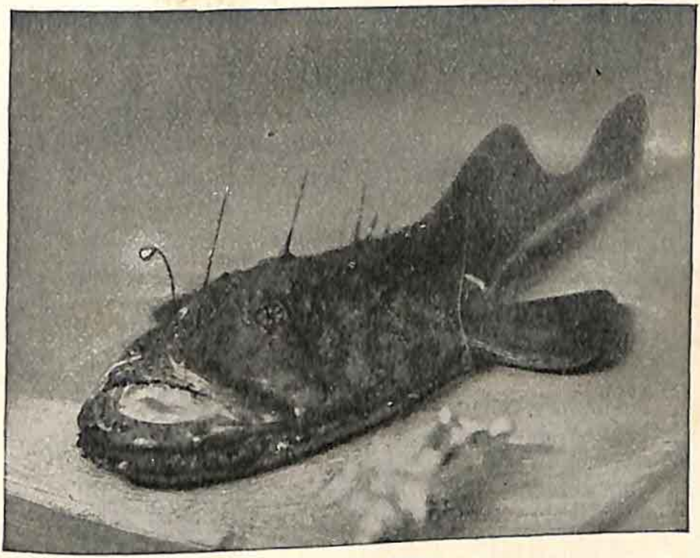


[From "*Readable Physiology and Hygiene*," Campbell, G. Bell & Sons, *Ltd.*

DEEP DIVING SUIT.

water is 64 lb. per cu. ft. Thus at a depth of 90 ft., the pressure due to the water is 90×64 lb. per sq. ft., i.e. $\frac{90 \times 64}{144} = 40$ lb. per sq. in. This pressure equals $\frac{40}{14 \cdot 7}$ or 2·7 atmospheres and thus the total pressure at this depth is 3·7 atmospheres.

The greatest pressure which the average man can conveniently withstand is about 4·5 atmospheres. As the pressure inside a rubber diving suit must equal that exerted on its outside, a diver



DEEP-SEA FISH.

used to be limited to a depth where the pressure is 4·5 atmospheres, i.e. to a depth of about 120 ft. This limit has been greatly extended by the invention of a steel diving suit with jointed limbs; this suit can withstand considerable pressure without extra inflation and so permit operations at depths of about 400 ft. It is heavy and cumbersome and its wearer is quickly fatigued.

For *observational* work, man can descend to much greater depths in a very strong steel sphere with small but thick glass windows. In such a sphere, Dr. Beebe has explored the sea at a depth of 2,200 ft., where, in the blackness of his watery surroundings, he saw strange luminous fishes with enormous mouths which allowed the great pressure of the water to be effective inside their bodies, thus counteracting the crushing effect of the pressure applied externally.

The utilisation of water pressure

(*a*) **Water supply.**—Water flows from a higher to a lower level because of a difference of pressure in the water at these levels.

Consider the application of this rule to the case of a town's water supply, a model of which is illustrated in Fig. 112. The delivery taps are at a level lower than that of the water in the reservoir. As there is equality of pressure at all points on the same level in a continuous liquid, the pressure at T, on the inside of the tap is equal to that at C. This is greater than the pressure of the air outside (by how much?), which is therefore insufficient to obstruct the flow of water when the tap is opened.

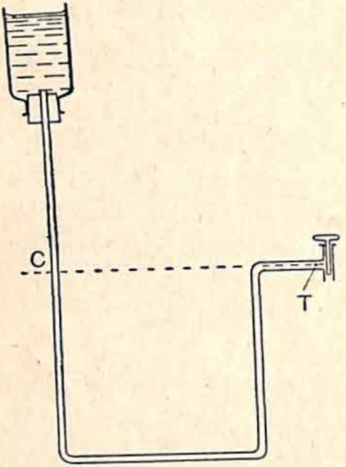


FIG. 112.

(*b*) **Water power machines.**—The energy of flowing water (p. 97) may be utilised in the performance of useful work by means of a water wheel. The old method was to couple the machine, e.g. a grain milling machine, direct to the shaft of the water wheel. With *flowing* water, an undershot wheel (Fig. 113)

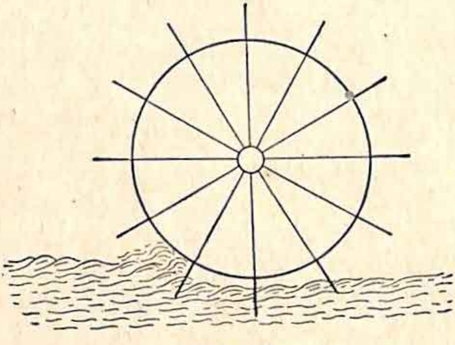


FIG. 113.

was used, but with *falling* water, the more efficient overshot wheel (Fig. 114) could be used.

These simple water wheels work too slowly for modern requirements, and in Britain machines are usually driven by steam

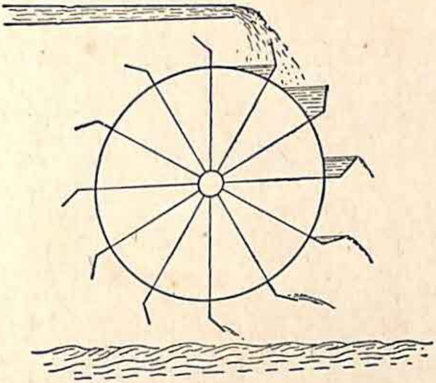


FIG. 114.

engines or electric motors, both of which ultimately derive their energy from coal. In countries where high waterfalls abound, e.g. in Switzerland, Norway or at Niagara, it is profitable to utilise the energy of the water to rotate an elaborate water wheel (a water turbine) and to couple the latter to one or more dynamos.

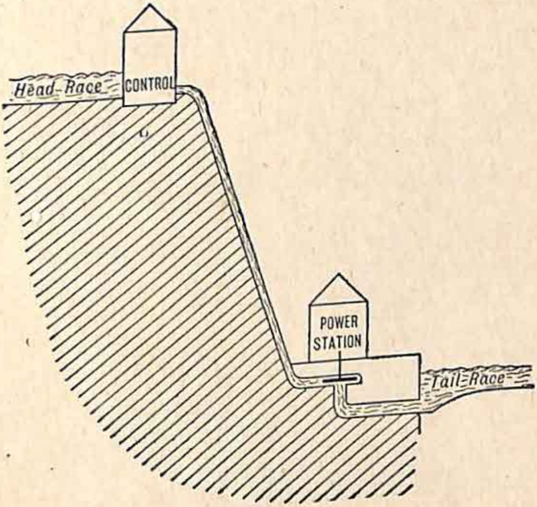
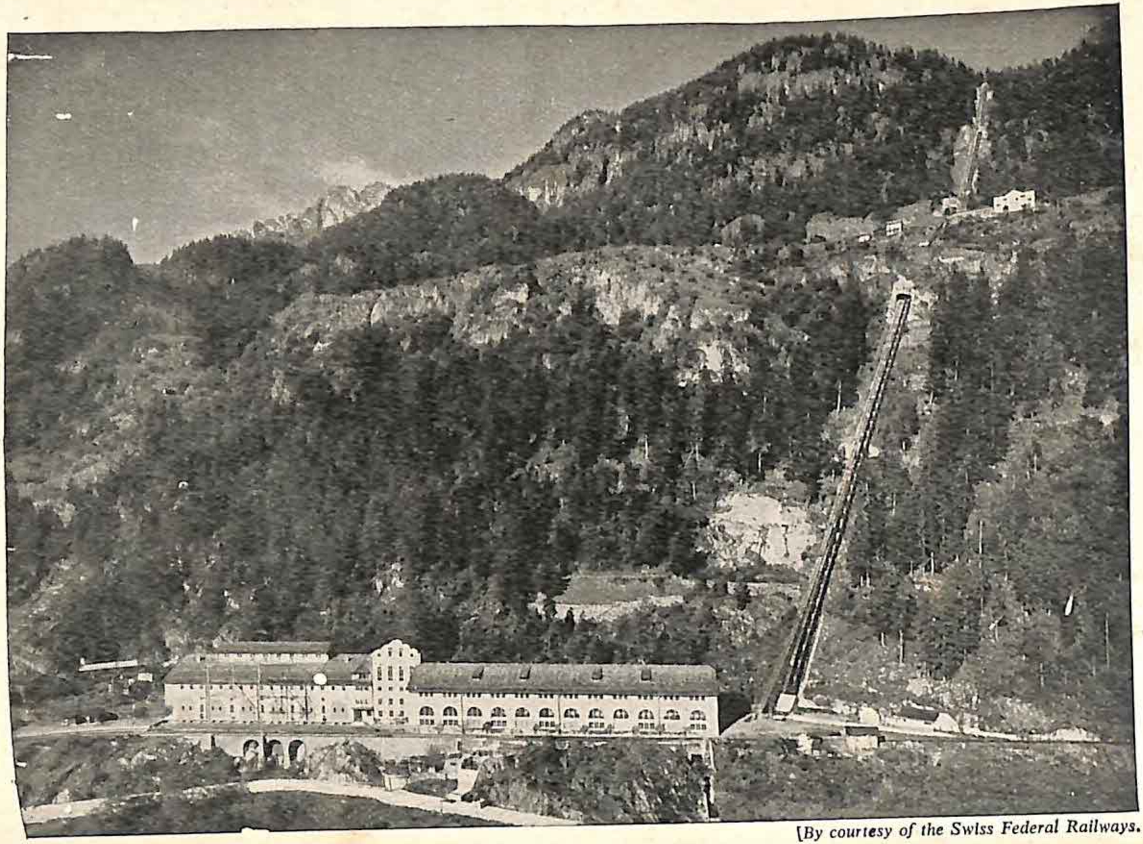

Head-Race
CONTROL
POWER STATION
Tail-Race

FIG. 115.



[*By courtesy of the Swiss Federal Railways.*

BARBERINI POWER STATION SWITZERLAND.

To maintain a steady rate of working of the turbine a large reserve of water is needed. This is obtained by building a dam across the valley above the waterfall. From this reservoir water flows in a channel (the head-race) to the edge of the precipice (Fig. 115), steel pipes guide its fall to the turbine and the spent water escapes by the waste channel or tail-race. Using this process, the hydro-electric station at Niagara supplies the electrical power required by over 500 neighbouring towns.

Pressure exerted by a gas

It is already known (Book I, p. 2) that the distinguishing property of a gas is that it is compressible. Now a gas, like a liquid, exerts pressure (cf. Expt. 3), and when it is squeezed into a smaller volume, the pressure of the gas is increased. Conversely, if a gas is allowed to expand, the pressure exerted by it is diminished. Is there a law connecting the volume which a gas occupies and the pressure which it exerts? Before proceeding with an experiment to investigate this question, two conditions must be fixed:

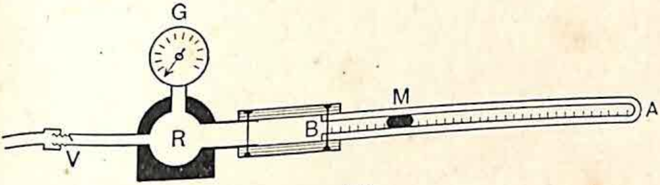


FIG. 116.

(*a*) The weight of gas used must not be altered.
(*b*) Its temperature must be kept constant.

Expt. D.—To investigate how the volume of a constant weight of air depends upon its pressure.

The apparatus consists of a graduated[1] tube AB, sealed at A and open at B (Fig. 116). The air under test is imprisoned by a bead of mercury M. By means of pressure tubing, the open end of the tube is connected to a reservoir R, in which the pressure can be increased by pumping in air, from an inflator, through the valve V. Also connected to the receiver is a pressure gauge G, graduated in lb. per sq. in. Since the tube is horizontal the pressure of the air on either side of the bead is the same.

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[1] The makers supply a linear scale below the tube. It pays to replace this permanently with a scale graduating the volumes in cubic units.

Note on the pressure gauge.—*When the valve V is unscrewed to bring the air on both sides of the bead to atmospheric pressure, the gauge reads zero. But the value of atmospheric pressure is not zero. The gauge is therefore reading too low by the value of atmospheric pressure at the time. As this varies only slightly from the normal value (p.* 154), *it will be sufficiently accurate in this experiment to obtain the actual pressure in the receiver by adding* 14·7 *lb. per sq. in. to the gauge reading.*

With the valve unscrewed, the volume of air in AM and its pressure are recorded in a table as indicated. The valve is then tightly screwed up and a little air pumped into the receiver. The gauge reading is taken, the true pressure calculated and the new volume AM read off. The procedure is repeated to obtain several pairs of corresponding pressures and volumes.

Actual pressure in receiver (p)	Volume of air (v)	Product, $p \times v$

To deduce a simple law connecting these pressures and their corresponding volumes, we must test each pair arithmetically in the same way to obtain a result which is constant. The corresponding values of pressure and volume are multiplied and the products entered in the third column. These products are sufficiently near for the small differences between them to be regarded as being due to experimental errors.

It is, therefore, reasonable to conclude that in the absence of experimental error, the product, pressure × volume is constant.

Boyle's Law

The conclusion to the foregoing experiment was discovered in 1660 by Sir Robert Boyle. Our expression of it really takes the form of a mathematical working rule or formula, $pv=k$. Stated in words, the law reads :

If the temperature and weight of a gas are kept constant, the volume occupied by the gas is *inversely proportional* to its pressure.

Boyle's Law and the storage of gases

When a large weight of gas is required for use at or about atmospheric pressure, it cannot be stored or conveyed at such a low pressure. It would take up too much space. The hydrogen required for barrage balloons (Book II, p. 10) is conveyed, highly compressed in steel cylinders, and the balloons filled where they are to be used. Oxygen for medical purposes is similarly compressed and conveyed to hospitals. A simple problem will illustrate the economy of this method of storage and transport.

An oxygen cylinder contains 0·5 *cu. ft. of gas at a pressure of* 120 *atmospheres. What volume of gas will it yield at a pressure of* 1 *atmosphere?*

The gas will change its volume in accordance with Boyle's Law.

Value of pv at 120 atmos. pressure$=120\times0{\cdot}5=60$.

Value of pv at 1 atmos. pressure$=1\times v$.

These products are equal. $\therefore v=60$ cu. ft.

In practice only 59·5 cu. ft. would be used. Why?

Measurement of high pressures

When it is necessary to measure a high pressure such as that of superheated steam in a high-speed locomotive or of the compressed air in a cylinder, a special type of pressure gauge is used. This is the **Bourdon gauge** and its working depends upon the tendency of a bent flexible tube to straighten out when inflated. In the Bourdon gauge the tube tapers from the open to the closed end (Fig. 117), and has an elliptical cross-section; the open end is connected to the cylinder or steam pipe, and the closed end C is permanently attached to the recording device. When the pressure is applied and the tube tends to straighten, C rises and rotates the rack around the fixed pivot R. This in turn

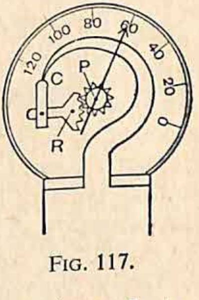


FIG. 117.

rotates the engaged pinion P to which is attached a pointer to record the appropriate pressure on the scale.

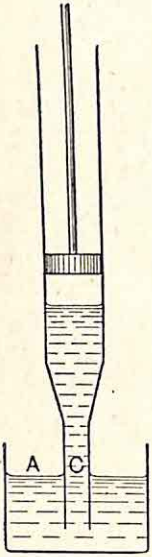


FIG. 118.

Pressure operations in everyday appliances

Amongst the many everyday appliances which depend upon the use of pressure or change of pressure, we shall consider two principal groups: (1) Water pumps, (2) Air pumps.

Water pumps

The syringe.—The syringe is the simplest of all pumps—a cylinder terminating in a nozzle and operated by a well fitting piston. When the nozzle is placed in water (Fig. 118) the pressure of the air on the water, at C, in the syringe is the same as that, at A, outside it. As the raising of the piston decreases the pressure of the air in the syringe, the atmospheric pressure on the water outside drives enough of it into the cylinder to keep the pressures at A and C, on the same level, equal (p. 152).

When the syringe is removed, the pressure in the water at the bottom of the nozzle is just equalised by atmospheric pressure. Compressing the air in the syringe, by pushing the piston down, increases the former pressure, and the water is forced out.

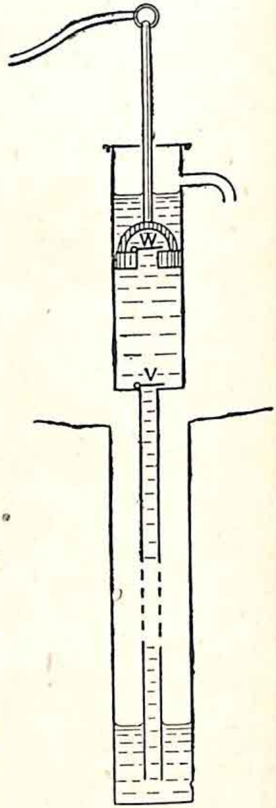


FIG. 119.

The lift pump raises water from a well and delivers it a few feet above ground level. It consists of a long pipe, the lower end dipping into the well water, the upper end capped by a cylinder in which a piston is operated by the pump handle (Fig. 119). Near the top of the cylinder is the spout from which the water is delivered. Attached to the base of the cylinder is a valve V which, when closed, covers the top of the pipe. The piston is also provided with a valve W which

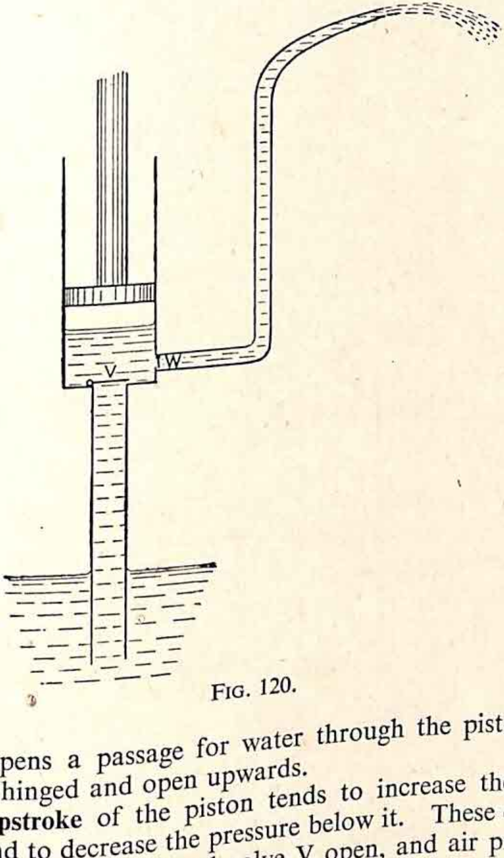


FIG. 120.

seals or opens a passage for water through the piston. Both valves are hinged and open upwards.

Every **upstroke** of the piston tends to increase the pressure above it and to decrease the pressure below it. These conditions keep the valve W closed and valve V open, and air pressure on the well water drives it up the pipe. Each **downstroke** reverses the pressure conditions, thus closing the valve V and opening valve W. A few strokes are necessary to get water up to the piston ; then, each downstroke forces water below the piston in the cylinder through the valve W, and each succeeding *upstroke lifts the transferred water* and delivers it from the spout.

During this delivery, the water column between the piston and the well is supported by atmospheric pressure on the well. Since the column of water which can be supported by the atmosphere is about 34 ft. high (cf. Ex. 4, p. 242), the height of the piston above the surface of the well water cannot exceed this figure.

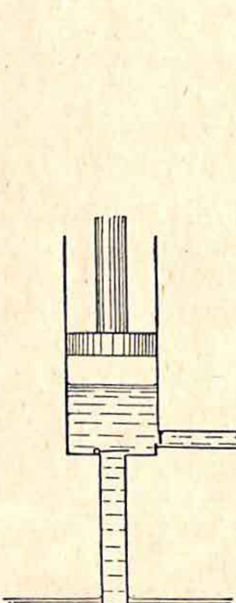


FIG. 121.

In practice, owing to leakage through and around the piston, some of the supporting effect of air pressure is wasted ; for this reason the height of the piston above the well is usually limited to 30 ft. or rather less.

The force pump draws water from a well and then forces it to a considerable height (Fig. 120, p. 167). It differs from the lift pump in certain important respects ; the piston is solid, and the upper valve W is placed in the delivery pipe which is connected to the bottom of the cylinder. The valve W opens from the cylinder into the delivery pipe, so that the pressure in this pipe tends to keep the valve closed.

The **upstroke** of the piston tends to reduce the pressure below it. This causes the valve V to open and water is raised from the well by atmospheric pressure. The **downstroke** increases the pressure below the piston, thus closing the valve V. The valve W is then opened and *water is forced from the cylinder through the delivery pipe*. A few strokes are necessary first to raise the water into the cylinder. The action as explained delivers water only on the downstroke of the piston. When a continuous stream is necessary, an air dome (Fig. 121) is coupled to the delivery pipe. On the downstroke, some of the water pushed out of the cylinder enters the dome and compresses the air in it; the rest escapes. On the upstroke, the supply is maintained by the expulsion of water from the dome.

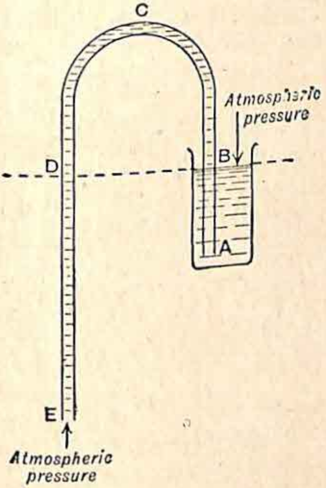


FIG. 122.

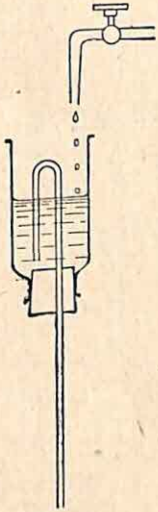
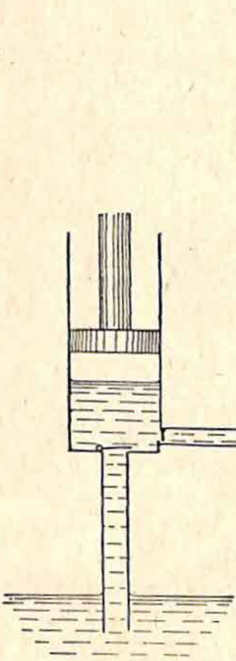


FIG. 123.

The height to which water may be drawn from the well is limited, as with a lift pump; the height to which it can be forced depends upon the strength and stability of the driving mechanism.

is about 34 ft. high (cf. Ex. 4, p. 242), the height of the piston above the surface of the well water cannot exceed this figure.



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In practice, owing to leakage through and around the piston, some of the supporting effect of air pressure is wasted ; for this reason the height of the piston above the well is usually limited to 30 ft. or rather less.

The force pump draws water from a well and then forces it to a considerable height (Fig. 120, p. 167). It differs from the lift pump in certain important respects ; the piston is solid, and the upper valve W is placed in the delivery pipe which is connected it. This causes

well by atmospheric pressure. The pressure below the piston, thus closing the valve V. The valve W is then opened and *water is forced from the cylinder through the delivery pipe.* A few strokes are necessary first to raise the

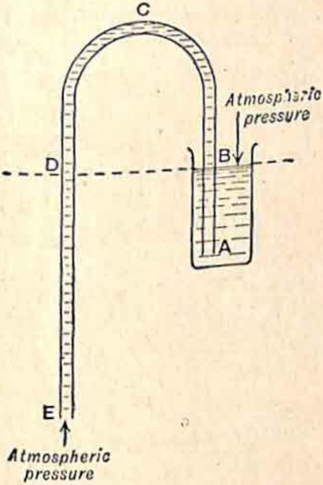


FIG. 122.

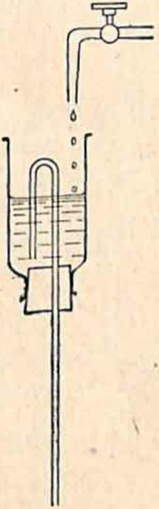


FIG. 123.

water into the cylinder. The action as explained delivers water only on the downstroke of the piston. When a continuous stream is necessary, an air dome (Fig. 121) is coupled to the delivery pipe. On the downstroke, some of the water pushed out of the cylinder enters the dome and compresses the air in it; the rest escapes. On the upstroke, the supply is maintained by the expulsion of water from the dome.

The height to which water may be drawn from the well is limited, as with a lift pump; the height to which it can be forced depends upon the strength and stability of the driving mechanism.

The siphon is a simple pump, working to *transfer a liquid to a lower level.* It is used chiefly to empty a vessel of water, when ordinary methods would be inconvenient or impracticable. For this purpose, a J-tube is filled with water and inverted with its short limb in the water to be transferred (Fig. 122, p. 169).

Since the pressure of the water in the siphon at D, on the same level as B, is equal to atmospheric pressure, the pressure must be greater than atmospheric at any point in the column between D and E. The upward pressure of the atmosphere on the water at E is insufficient to support this greater pressure of the water, which consequently flows out of the siphon.

Siphons constructed to discharge water from a tank automatically at intervals are now widely used. The bend of the tube is completely within the tank (Fig. 123, p. 169). As the water is slowly replenished after a discharge, it rises in the short tube of the siphon and as soon as the bend is full the action of the siphon empties the tank.

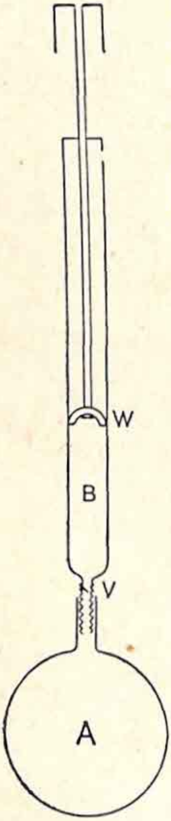


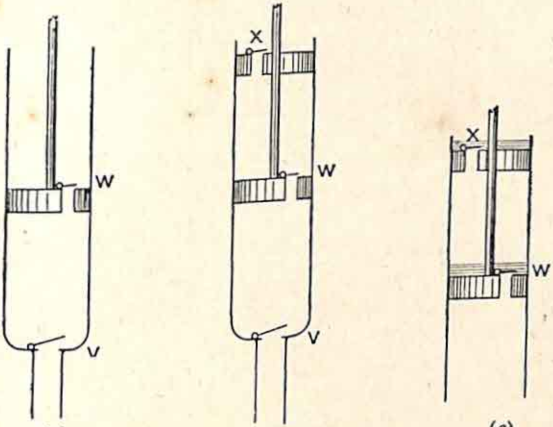
FIG. 124.

Air pumps

The compression pump.—A simple compression pump, e.g. a football inflator (Fig. 124), consists of a barrel, a piston and piston rod, and two valves. The piston is a washer of leather W, well oiled to render it flexible so as to operate as a valve. This washer is wider than the barrel and is curved inwards. A second valve V controls the air in the receiver A.

On the **compression stroke**, the pressure in B is increased. When it exceeds the pressure in A, the valve V opens and air passes into A. The increased pressure in B keeps the curved piston, acting as its own valve, tightly pressed against the barrel so that the air does not escape outwards. On the **return stroke**, the pressure in B immediately decreases and the air in A closes the valve V. When the pressure in B is just less than atmospheric, air above the piston opens the valve W and enters B. At the end of the stroke, the barrel contains air at atmospheric pressure.

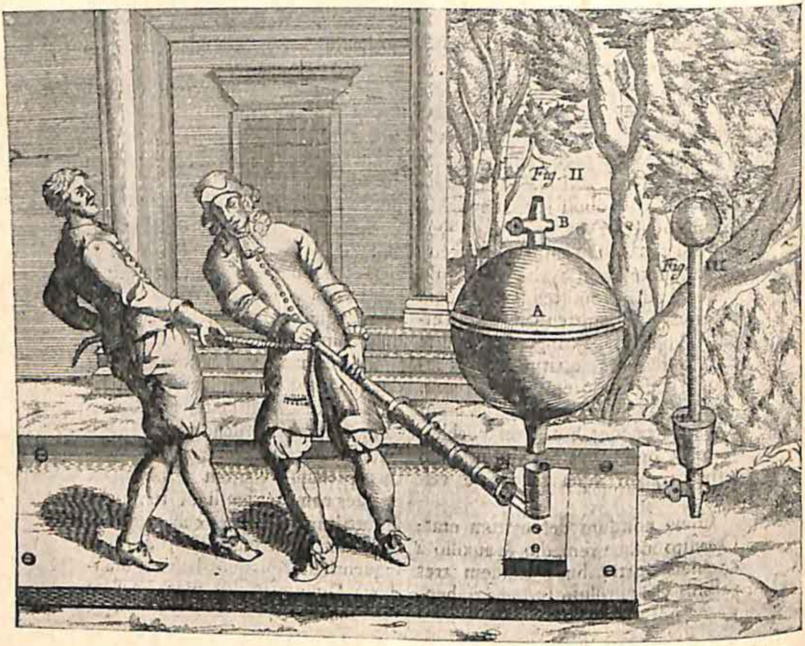
At the end of the compression stroke some compressed air always remains between the piston and the valve V. When the pressure in A has been made as great as the pressure of this air, V does not open and no more air can be pumped into the receiver.



(*a*) (*b*) (*c*)

FIG. 125.

The exhaust pump.—In its simplest form, the exhaust pump (Fig. 125*a*) is similar in design to the compression pump; in its mode of action it differs in one important respect—its valve movements are opposite to those of the compression pump. The **exhaust stroke** works the piston against atmospheric pressure and lowers the pressure in the barrel and the receiver. Which valve is open and which closed? The **return stroke** leaves the pressure in the receiver unchanged and restores the air remaining in the barrel to atmospheric pressure. Which valve is now open and which closed? As there is always a little air left in the barrel at the end of the return stroke, it will be evident that evacuation of the receiver finishes when the pressure of this air cannot be reduced, by the exhaust stroke, below the pressure of the air still in the receiver.



[*British Museum Photo : Fleming.*

FIG. 126.

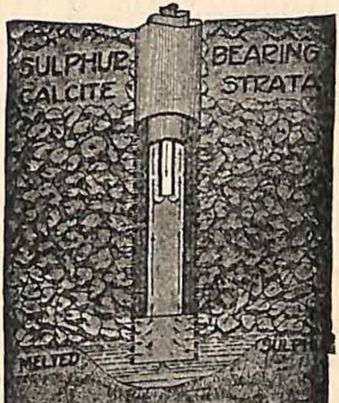
This was the type of pump invented by von Guericke to evacuate his copper globe. The illustration (Fig. 126) shows that it took two men to work this pump. In the last stages of evacuation, on the outside of the piston there is a pressure of nearly 15 lb. per sq. in. ; on the inside there is hardly any pressure at all. If r in. is the radius of the piston, then the pull required in these circumstances would be nearly $15\pi r^2$ lb., and this may be quite large enough to require the continued efforts of two men. Smeaton overcame the need to employ such a large pull on the piston by closing the top of the barrel with a cap (Fig. 125*b*), fitted with a valve X which opens outwards. As the piston is pushed downwards the air pressure closes X and the resulting decrease of pressure above the piston relieves it from the thrust of the atmosphere on the succeeding exhaust stroke. In the Geryk pump, used in our early experiments on air pressure (Book I, Chap. 14), the efficiency is further increased by providing layers of oil on the piston and cap to minimise leakage at the end of the exhaust stroke (Fig. 125*c*).

CHAPTER 13

SULPHUR. SULPHUR DIOXIDE. SULPHURIC ACID

Sulphur

Several different kinds of the element sulphur are known, but the only common varieties are **roll sulphur** and **flowers of sulphur.** This element is found free in nature; it also occurs combined with metals in various sulphides, some of the most important being *iron pyrites*, FeS_2, *zinc blende*, ZnS, and *galena*, PbS.



[Reproduced by permission of the Texas Gulf Sulphur Co.

FIG. 127.

The extraction of sulphur

The bulk of the sulphur needed in commerce is obtained from natural deposits; most of the mineral sulphides are used as sources of the metals they contain. Two methods are employed in extracting sulphur.

(1) In the older or Sicilian process the native sulphur is quarried, then stacked into heaps in special kilns which have a sloping floor. The sides of these kilns are permanent; the top consists of rubbish from previous extractions. A certain amount of air is admitted and the sulphur ignited. Some of the sulphur is burnt, giving out heat which causes the rest to melt and run away from the impurities in the mineral. The molten sulphur is run off from the bottom of the kiln and further purified by distillation.

(2) In the Frasch process, used in America, three concentric pipes are sunk into the sulphur bed (Fig. 127). Superheated water, which melts the sulphur, is passed down the space between the two outer pipes, while compressed air, pumped down the centre pipe, forces a mixture of molten sulphur and water up through the space between the two inner tubes. This mixture is collected in vats and the sulphur is separated when it has solidified. No further purification is needed in this process.

Roll sulphur

This kind of sulphur is obtained by casting liquid sulphur into sticks. It is a brittle, yellow solid, which is insoluble in water, but soluble in carbon disulphide. If a solution of sulphur in this liquid is allowed to evaporate slowly octahedral crystals are deposited. Roll sulphur is generally called rhombic sulphur.

When roll sulphur is heated carefully, it melts at 115° C. giving a mobile, amber-coloured liquid. On raising the temperature, the liquid darkens to a chestnut colour and it becomes so viscous that the tube containing it can be kept inverted for some time. At higher temperatures the liquid becomes very dark brown and less viscous ; finally it boils at about 440° C. giving a reddish-brown vapour. On cooling, the liquid passes through these remarkable changes in the reverse order.

Sulphur is a bad conductor of heat and electricity ; it is sometimes used as an insulator.

Flowers of sulphur

This fine, yellow powder is obtained by cooling sulphur vapour quickly. Flowers of sulphur is a mixture of two kinds of sulphur ; one is soluble in carbon disulphide, the other insoluble in this liquid. The soluble part consists of rhombic sulphur, the insoluble part is amorphous (non-crystalline) sulphur.

The chemical properties of sulphur

Sulphur is a non-metal and it does not react with dilute acids. It burns feebly in air, more vigorously in oxygen, with a pale blue flame, giving sulphur dioxide.

Many metals combine readily with sulphur. If an intimate mixture of two parts by weight of finely divided iron filings and one part of powdered sulphur is put into a hard-glass test-tube and the tube is heated at the bottom, a red glow spreads throughout the mass. The product is ferrous sulphide:

$$Fe + S \rightarrow FeS.$$

This solid readily dissolves in dilute hydrochloric acid, a gas with the odour of rotten eggs being evolved; this gas, hydrogen sulphide, is present in the atmosphere in small quantities and causes silver objects to tarnish. If you carry a silver coin with an india-rubber in the same pocket, you will find that the coin becomes black. This is the result of the combination of sulphur from the rubber (below) and silver in the coin to give silver sulphide.

The uses of sulphur

About 2 million tons of sulphur are extracted annually; among its various uses are the following:

(1) As a medicine, it is taken internally in the form of tablets, or applied as an ointment in the treatment of certain skin diseases.

(2) To combat certain plant diseases, e.g. a fungus which attacks the vine; it is dusted on to the plant as a fine powder.

(3) In the manufacture of friction matches, sulphur is made into phosphorus sulphide; this is the combustible compound in the head of the match.

(4) In making gunpowder; this mixture contains about 10 per cent. of sulphur.

(5) In the production of sulphur dioxide and its derivatives (p. 176).

(6) In the **vulcanisation** of rubber, a process which causes rubber to retain its flexibility over a wide range of temperature. Crude rubber is ground between two heavy horizontal rollers, which almost touch and rotate in opposite directions at different speeds. The rubber forms a sheet on the slower roller. It is cut off, reground and sulphur with other filling materials is worked into it. Vulcanisation is effected, after this mixing process, by heating to a temperature of about 140° C. for some time. Thus, in the case of a motor tyre, the heating is done while the tread is being put on the tyre in a metal mould.

Vulcanisation of rubber using about 40 per cent. of sulphur produces ebonite, a hard, black substance which is a good insulator; it was formerly much used as a plastic, e.g. for making fountain pens.

The preparation of sulphur dioxide, SO_2

Samples of this gas are prepared by the following simple methods:

(1) Jars of oxygen (from a cylinder) are collected by displacing air upwards, then burning sulphur in a deflagrating spoon is lowered into each jar till the bright pale blue flame disappears.

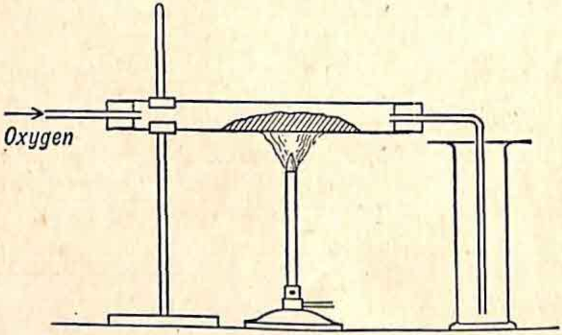


FIG. 128.

(2) A slow stream of oxygen is passed through a hard-glass tube containing some powdered iron pyrites. On heating the tube, the solid burns brightly and the gas is collected as indicated in Fig. 128. The reaction is:

$$4FeS_2+11O_2\rightarrow 2Fe_2O_3+8SO_2.$$

This method is employed in making sulphur dioxide on a large scale; various sulphides are used while air is substituted for oxygen. The resulting gas is mixed with nitrogen and oxygen, but in most large scale operations for which sulphur dioxide is required, it is not necessary to isolate the pure gas.

The properties of sulphur dioxide

Sulphur dioxide is a colourless gas which has a choking smell; it is poisonous. The gas is fairly easily condensed to a colourless liquid by passing it through a U-tube cooled in a freezing mixture of ice and salt. To illustrate the following properties of the gas, jars are preferably filled from a "siphon" in which liquid sulphur dioxide is stored under pressure.

When a jar of sulphur dioxide is opened under water, the latter rises steadily in the jar, showing that the gas is quite soluble. The solution is acid to litmus.

Sulphur dioxide is much denser than air. It does not burn and a lighted taper is extinguished in the gas. Sulphur dioxide, however, combines with oxygen to form the trioxide under special conditions (p. 178).

If red rose or peony petals (or a filter paper soaked in rosaniline acetate solution) are allowed to stand in a jar of the gas, the petals are bleached. When the bleached petals are exposed to the air for some time, the colour returns, showing that the bleaching is not permanent.

Sulphur dioxide only bleaches in the presence of water; in bleaching possibly the gas first reacts with water thus:

$$2H_2O+SO_2 \rightarrow H_2SO_4+2H \text{ (nascent).}$$

The nascent (or new-born) hydrogen then reacts with the colouring matter to give a colourless compound. The return of the colour in air is probably due to oxygen reversing this reaction.

Sulphurous acid, H_2SO_3

This acid is only known in solution; it is prepared by passing sulphur dioxide into water, when the gas combines with some of the water:

$$H_2O+SO_2 \rightarrow H_2SO_3.$$

The salts of this acid are called sulphites. Both acid (or bisulphites) and normal sulphites can be made, e.g. sodium hydrogen sulphite, $NaHSO_3$, and normal sodium sulphite, Na_2SO_3.

Calcium bisulphite is a substance of commercial importance; it is made by passing sulphur dioxide into milk of lime (a suspension of slaked lime in water) till the liquid smells of the gas:

$$Ca(OH)_2+2SO_2 \rightarrow Ca(HSO_3)_2.$$

The uses of sulphur dioxide

(1) Liquid sulphur dioxide is used as a refrigerating agent in the same way as liquid ammonia. (Book II, p. 14.)

(2) Since the gas is poisonous, it is sometimes used as a germicide, e.g. in disinfecting a room in which a patient has had scarlet fever.

(3) Although sulphur dioxide is not such a powerful bleaching agent as chlorine, it does not rot the materials to be bleached. It is therefore used to bleach straw, wool and silk. The yellowness of old straw hats and woollen blankets is due to oxygen in the air reversing the bleaching process (p. 177).

(4) Calcium bisulphite is used extensively in making chemical wood pulp for the manufacture of paper and artificial silk. After removing the bark, the wood is chopped into small pieces and digested with calcium bisulphite solution. This substance dissolves the resinous substances which bind the wood fibres. The liquid is next run off from the wood fibres, which are then macerated, and the resulting suspension of fibres in water is run on to a travelling wire-cloth belt. By means of a pump, the water is " sucked " through the belt leaving a sheet of wood pulp which is dried by passing through hot rollers.

(5) The chief use of sulphur dioxide is in the manufacture of sulphuric acid.

The preparation of sulphuric acid, H_2SO_4

Sulphuric acid is prepared by first making sulphur trioxide, SO_3; this readily combines with water to produce the acid. **Sulphur trioxide** is obtained by passing dry sulphur dioxide mixed with oxygen through dry platinised asbestos heated to about 450° C. The finely divided platinum coating the asbestos acts as a catalyst in the following reaction :

$$2SO_2 + O_2 \rightarrow 2SO_3.$$

The apparatus required (Fig. 129) is erected in a fume cupboard. Sulphur dioxide is obtained from a " siphon " and oxygen from a cylinder. The gases are bubbled slowly at about the same rate through tube A, which contains concentrated sulphuric acid, and the platinised asbestos is heated to a low red heat. Sulphur trioxide is obtained in tube B, which is cooled in a freezing mixture, as a white solid. Uncondensed sulphur trioxide passing from the exit tube gives dense white fumes in the damp air. To examine the solid in B, the tube must be corked immediately it is disconnected from the rest of the apparatus.

To obtain sulphuric acid, water is added very carefully drop by drop to the trioxide. A violent reaction occurs with much fuming as the trioxide combines with the water :

$$SO_3 + H_2O \rightarrow H_2SO_4.$$

If a little of the acid is smeared on some paper by means of a splint, the paper readily chars on warming over a Bunsen flame. The acid if diluted a little will dissolve zinc with the evolution of hydrogen.

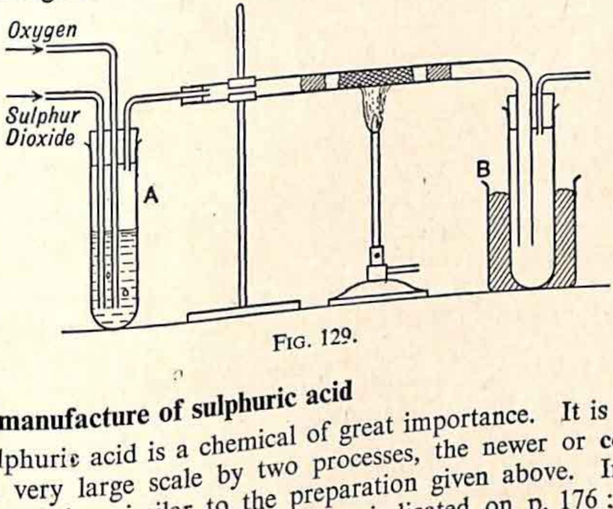


FIG. 129.

The manufacture of sulphuric acid

Sulphuric acid is a chemical of great importance. It is made on a very large scale by two processes, the newer or **contact process** being similar to the preparation given above. In this process, sulphur dioxide is made as indicated on p. 176 ; it is mixed with excess air as it is being produced. The mixed gases have then to be purified with great care to avoid damaging the expensive catalyst. As the mixture of sulphur dioxide, oxygen and nitrogen passes through the heated platinum catalyst, sulphur trioxide is formed. The gases are cooled, then passed up towers down which 98 per cent. sulphuric acid trickles. The trioxide readily dissolves in this acid increasing its concentration, and the required quantity of water is mixed with the acid coming from the bottom of the tower to keep the concentration at 98 per cent.

The properties of sulphuric acid

Concentrated sulphuric acid is a colourless, oily liquid ; it is still often called *oil of vitriol.* It has no odour and does not fume. When exposed to the air, this acid readily takes up moisture, so that it is used for drying gases with which it does not react.

Sulphuric acid is much denser (sp. gr. 1·84) than water with which it mixes in all proportions, a good deal of heat being evolved in the process. In diluting sulphuric acid, the acid must be added to water, a little at a time, with constant stirring. If water is added to the acid, the water tends to float, and so much heat may be given out where the liquids meet that the water boils and shoots out of the containing vessel, bringing some acid with it.

Concentrated sulphuric acid rapidly attacks the skin and clothing, so that it must be handled with care.

If a drop of the acid is heated in a dish, it gives thick, white, choking fumes of sulphur trioxide.

When cold, concentrated sulphuric acid does not react with metals, but it attacks most metals when it is hot. Thus, when copper is heated with the concentrated acid a vigorous reaction takes place ; sulphur dioxide is given off and a black solid, cuprous sulphide, is an obvious product. Copper sulphate, too, is produced in the reaction which is generally represented thus :

$$Cu+2H_2SO_4 \rightarrow CuSO_4+SO_2+2H_2O.$$

Concentrated sulphuric acid removes the elements of water from certain substances ; it is a **dehydrating agent.** Thus, addition of the concentrated acid to a syrup of cane sugar produces violent frothing, a black mass of sugar carbon remains.

$$C_{12}H_{22}O_{11}-11H_2O \rightarrow 12C.$$

The action of sulphuric acid on paper, wood and flesh is of this type. Similarly, on warming blue copper sulphate, $CuSO_4.5H_2O$, with the concentrated acid, white copper sulphate, $CuSO_4$, is obtained.

Concentrated sulphuric acid reacts with salts of most other acids to form the metallic sulphate, the other acid being set free. Thus, nitric acid is produced from nitrates, and hydrogen chloride from chlorides.

The preparation of sulphates

The salts obtained from sulphuric acid all contain the radical $>SO_4$, valency 2; they can be prepared in various ways. The more important methods are:

(1) By dissolving a metal, e.g. zinc or iron, in dilute sulphuric acid. Copper does not dissolve in the dilute acid. The reaction with iron is:

$$Fe+H_2SO_4 \rightarrow FeSO_4+H_2.$$

(2) By dissolving a basic (metallic) oxide, e.g. copper oxide, in dilute sulphuric acid. In this case, the reaction is:

$$CuO+H_2SO_4 \rightarrow CuSO_4+H_2O.$$

(3) By neutralising dilute sulphuric acid with an alkali, e.g. caustic soda:

$$2NaOH+H_2SO_4 \rightarrow Na_2SO_4+2H_2O.$$

(4) By dissolving a metallic carbonate in dilute sulphuric acid. Thus, the reaction with zinc carbonate is:

$$ZnCO_3+H_2SO_4 \rightarrow ZnSO_4+H_2O+CO_2.$$

Calcium sulphate, which is not very soluble in water, is obtained as a white precipitate when sulphuric acid or a solution of a sulphate is added to a solution of calcium chloride:

$$CaCl_2+H_2SO_4 \rightarrow CaSO_4+2HCl.$$

EXPT. 1.—*Preparation of ferrous sulphate*, $FeSO_4.7H_2O$.

Weigh roughly 2–3 grm. of iron filings, add to 50 c.c. dilute sulphuric acid in a flask, and warm but do not boil. Continue till the iron has dissolved and little or no hydrogen is being given off. (If the liquid tends to become brown, a little more acid should be added.) Filter the liquid. Concentrate the pale green filtrate and leave it to cool. Green crystals of ferrous sulphate are obtained.

EXPT. 2.—*Preparation of copper sulphate*, $CuSO_4.5H_2O$.

Weigh 3–4 grm. of black copper oxide and warm with 50 c.c. dilute sulphuric acid in a beaker. If the oxide does not dissolve completely, add a little more acid till a clear blue solution is obtained. Proceed as in Expt. 1. Blue crystals of copper sulphate are deposited.

EXPT. 3.—*Preparation of sodium sulphate*, $Na_2SO_4.10H_2O$.

Take roughly 20 c.c. of caustic soda (sodium hydroxide) solution in a beaker. Add dilute sulphuric acid gradually to this and stir with a glass rod. After each addition, remove a drop of liquid with the rod on to a small piece of blue litmus paper. Continue till the litmus *iust* becomes red. Concentrate the resulting solution and leave it to crystallise. Sodium sulphate crystals are colourless.

EXPT. 4.—*Preparation of zinc sulphate*, $ZnSO_4.7H_2O$.

Weigh roughly 6 grm. of zinc carbonate and add, little by little, to 50 c.c. warm dilute sulphuric acid in a beaker. Continue till the solid no longer dissolves and there is no further evolution of carbon dioxide. Clear the liquid by adding a little more acid, then concentrate and crystallise. Zinc sulphate crystals are colourless.

EXPT. 5.—*Preparation of calcium sulphate*, $CaSO_4.2H_2O$.

Make a fairly concentrated solution of calcium chloride in a test-tube. Add dilute sulphuric acid to it and shake. A white precipitate of calcium sulphate is obtained.

The uses of sulphuric acid

This acid is manufactured on a considerable scale, and the following are some of its more important uses :

(1) In the manufacture of calcium superphosphate and ammonium sulphate, both of which are important artificial manures. **Calcium superphosphate** is a mixture of calcium hydrogen phosphate and calcium sulphate ; it is made by treating calcium phosphate with sulphuric acid :

$$Ca_3(PO_4)_2 + 2H_2SO_4 \rightarrow Ca(H_2PO_4)_2 + 2CaSO_4.$$

Superphosphate is much more soluble in water than ordinary calcium phosphate (bone ash) and is therefore a quick-acting manure.

Ammonium sulphate is made on a large scale, but only a certain proportion is now produced by neutralising sulphuric acid with a solution of ammonia.

(2) In refining oils. The oils employed to lubricate the engines of motor cars are agitated with concentrated sulphuric

acid. The acid removes certain substances which tend to produce a sludge in the lubricating system of an engine.

(3) In manufacturing nitric acid from sodium nitrate, and hydrochloric acid from salt ; sodium sulphate is an important by-product used in manufacturing glass.

(4) In accumulators for cars, electric lighting sets, wireless sets, etc.

(5) In making glucose from starch (p. 14) for the manufacture of sweets and confectionery.

(6) For " pickling " iron, i.e. dissolving off the rust, previous to galvanising with zinc or plating with tin.

(7) In the manufacture of explosives and substances required in making dyes (p. 58).

CHAPTER 14

SALT. HYDROCHLORIC ACID. CHLORINE. CAUSTIC SODA

Common salt (sodium chloride), $NaCl$

Ordinary salt is present in sea-water to the extent of about 2½ per cent., and it has been estimated that from the salt dissolved in the sea all the mountain ranges in the world could be built up.

Salt mixed with variable quantities of earthy matter is found in layers or beds within the earth's crust in several countries. In England there are deposits of rock salt which are as much as 500 ft. thick. Some of the most extensive deposits are found in Poland.

The extraction of salt

Salt is obtained (1) from sea-water, (2) by mining rock salt, and chiefly (3) by flooding the salt-bed with water and pumping up the resulting brine.

The production of salt from sea-water is carried out where the heat of the sun and drying winds, e.g. in North Africa, can be used to evaporate the water.

To extract salt from rock salt, the latter is mixed with water to obtain a salt solution together with suspended impurities. The latter are removed by filtration, then the salt is isolated by evaporating the brine. Rapid evaporation under reduced pressure gives fine table salt ; slow evaporation in open pans yields coarse salt suitable for packing fish.

The uses of salt

Over 20 million tons of salt are extracted each year in various parts of the world, so that salt is obviously a substance of vast importance. We are all familiar with the use of salt in seasoning food, for curing ham and bacon, and for preserving fish and sometimes meat.

Salt is the substance from which large quantities of washing soda and caustic soda are made, and it is also the source of chlorine and hydrochloric acid.

The preparation of hydrogen chloride, HCl

To obtain this gas, the apparatus shown in Fig. 130 is set up. The bottom of the flask is covered with lumps of rock salt (or "fused" salt), then concentrated sulphuric acid is allowed to drop on to the salt from the tap-funnel. The gas is given off at once, and, when the sides of the flask have become wet with acid, gentle heating produces a more rapid evolution of the gas.

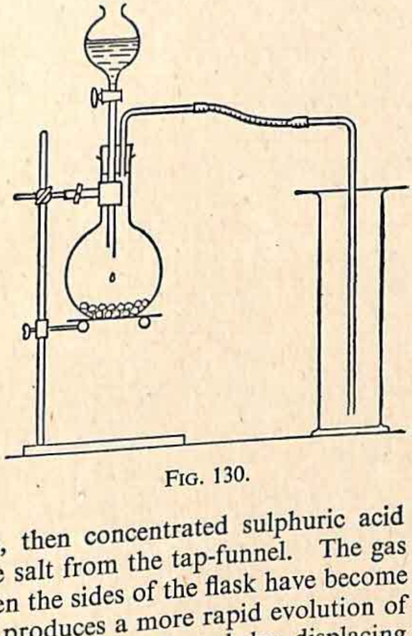


FIG. 130.

Hydrogen chloride is collected by displacing air upwards. White fumes escaping from the mouth of the jar show that the jar is full of gas. The reaction is :

$$NaCl+H_2SO_4 \rightarrow NaHSO_4+HCl.$$

The properties of hydrogen chloride

Hydrogen chloride is a colourless gas, which fumes in damp air ; it has a choking smell.

If a dry flask is filled with hydrogen chloride, then closed with a rubber stopper fitted with a tube drawn out to a jet (Fig. 131), on plunging the flask into a jar of neutral litmus solution a fountain is formed within the flask and the litmus becomes red. This experiment shows that hydrogen chloride is very soluble in water and that the solution is acid—hydrochloric acid.

Hydrogen chloride is denser than air ; it does not burn or support ordinary combustion.

If a jar of hydrogen chloride is brought mouth to mouth with a jar of ammonia, the two gases combine giving a dense white smoke. This, on standing, settles as a white solid—ammonium chloride :

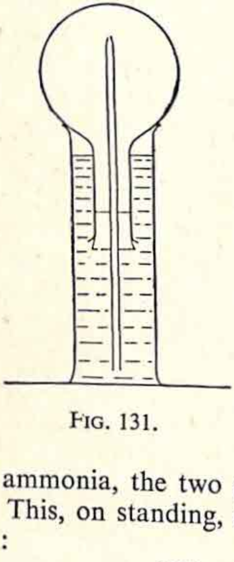


FIG. 131.

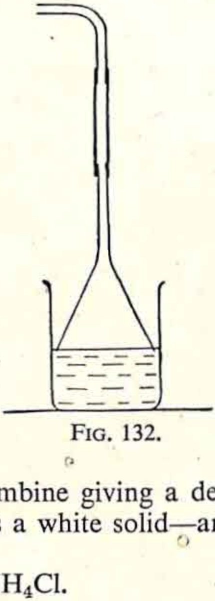


FIG. 132.

$$NH_3+HCl \rightarrow NH_4Cl.$$

The preparation of concentrated hydrochloric acid

This acid is a saturated solution of hydrogen chloride in water. As the gas is very soluble in water, and concentrated sulphuric acid is used in its preparation, it is essential to avoid " sucking back " as the gas is dissolving. The simple apparatus in Fig. 132 consists of a funnel, i.e. a wide delivery tube, which just fits into a beaker, and the rim of the funnel just dips below the surface of the water. With this arrangement it is possible for the liquid to rise only a little way inside the funnel before the outside liquid-level falls to the rim, thus admitting air.

The properties of concentrated hydrochloric acid

Concentrated hydrochloric acid is a colourless liquid which fumes especially when the air contains much water vapour. The fuming is due to the loss of hydrogen chloride. This acid is a little denser than water.

Most of the reactions of concentrated hydrochloric acid are like those of the dilute acid, except that they are more vigorous. The interaction of the acid with metals, basic oxides, alkalies, and carbonates is dealt with in the following section.

The concentrated acid, unlike the dilute acid, reacts with peroxides, e.g. manganese dioxide, producing the gas chlorine.

The preparation of metallic chlorides

The salts derived from hydrochloric acid, i.e. the chlorides, are made by methods like those used to obtain sulphates (p. 181).

(1) By dissolving a metal, e.g. zinc or iron (not copper), in hydrochloric acid. The reaction with zinc is :

$$Zn+2HCl \rightarrow ZnCl_2+H_2.$$

(2) By dissolving a basic (or metallic) oxide, e.g. copper oxide, in hydrochloric acid. The reaction with copper oxide is :

$$CuO+2HCl \rightarrow CuCl_2+H_2O.$$

(3) By neutralising hydrochloric acid with an alkali ; e.g. caustic soda reacts thus :

$$NaOH+HCl \rightarrow NaCl+H_2O.$$

(4) By dissolving a metallic carbonate in hydrochloric acid ; e.g. copper carbonate reacts thus :

$$CuCO_3+2HCl \rightarrow CuCl_2+H_2O+CO_2.$$

Silver chloride is insoluble in water and dilute nitric acid, so that it is obtained as a white curdy precipitate when a solution of silver nitrate is added to hydrochloric acid or a solution of any chloride :

$$AgNO_3+HCl \rightarrow AgCl+HNO_3.$$

EXPT. 1.—*Preparation of zinc chloride*, $ZnCl_2$.

Weigh roughly 3 grm. of granulated zinc and warm with 50 c.c. dilute hydrochloric acid in a beaker. When as much zinc as possible has dissolved, i.e. no more hydrogen is being evolved, filter the liquid and evaporate the filtrate *just to dryness* in a dish. Zinc chloride is a white solid.

EXPT. 2.—*Preparation of copper chloride*, $CuCl_2$.

Weigh roughly 2 grm. of black copper oxide and warm with 30 c.c. dilute hydrochloric acid in a beaker. If the oxide does not all dissolve, add a little more acid till a clear green solution is obtained. Evaporate this solution to dryness in a dish. The product, anhydrous copper chloride, is brown; on adding a drop or two of water it becomes green, $CuCl_2.2H_2O$.

EXPT. 3.—*Preparation of silver chloride*, AgCl.

Add dilute hydrochloric acid to silver nitrate solution in a test-tube. Close the tube and shake. Let the curdy precipitate settle and pour off the bulk of the liquid. Transfer the silver chloride to a piece of filter paper and expose to sunlight if possible. Notice that the white silver chloride becomes mauve and even purple if the light is bright.

Prepare another sample of silver chloride in a test-tube as above and then shake it with a solution of "hypo" (sodium thiosulphate). Note that the silver chloride dissolves in this solution.

The simple chemistry of photography

If a solution of potassium bromide, KBr, is added to a solution of silver nitrate, a pale yellow precipitate of silver bromide, AgBr, is obtained. This silver bromide, like silver chloride, undergoes a change when it is exposed to light, and it is the action of light on these silver salts which is the basis of photography.

For photographic purposes it is essential to prepare the silver bromide or chloride in the form of a very fine suspension. This is done by mixing hot solutions of potassium bromide or chloride and silver nitrate which contain gelatine. This suspension is prepared in red light, which does not affect the silver salt. The bromide suspension is then used for coating glass plates or celluloid films for making negatives, while specially prepared paper for printing positives by artificial light is coated with a suspension of silver bromide or chloride, or a mixture of the two. The preparation of films and sensitised paper has, of course, to be done in red light, and they must be packed in such a way that no white light can reach the silver salt.

In preparing a negative, the film is fixed in the camera and the position of the lens is adjusted so that a sharp image of the object to be photographed falls on the film. In taking a snapshot the shutter is opened for, say, $\frac{1}{25}$ second, and during this brief exposure light reaching the film affects the silver bromide, the extent of the change depending upon the intensity of the light. Examination of the film in red light does not reveal any obvious change. After exposing the film, it is subjected to the action of a solution containing a mixture of chemicals in the process called **developing.** The developer changes silver bromide which has been affected by light into metallic silver, but it does not affect unchanged silver bromide. The result of developing is that parts of the film upon which light fell become dark, the darkness depending upon the intensity of the light.

After washing the film, the next step is to remove unchanged silver bromide ; this process is called **fixing.** The film is treated with a solution of sodium thiosulphate (hypo) in which silver bromide dissolves chemically. During developing and fixing, only red light may be used. Finally, the film is washed and dried, the result being a **negative**, i.e. an image in which light parts of the object are dark and vice versa.

To produce a print or positive, the negative is fixed in a suitable frame in contact with a sheet of sensitised paper. For printing by artificial light this operation can be done in yellow light or in a screened part of the room well away from any light. An exposure of a few seconds at a short distance from an electric light is all that is necessary. The time of the exposure depends upon the candle-power of the lamp, the distance from it, the density of the negative and the type of paper, so that no precise figures can be given. It is well to work at a fixed distance with one particular lamp and to vary the time of exposure till satisfactory prints are obtained.

After making the exposure, the paper is removed from the frame and examination shows that it does not appear to have changed. On treating with a developer, silver salt affected by light is reduced to silver, then the paper is removed to a fixing bath, so that the " hypo " solution will dissolve unchanged silver salt. Developing takes about 30 seconds, fixing about 10 minutes. Finally, the paper is washed in running water for about an hour. In making the positive, little light passes through dark parts of the negative and vice versa, so that the print is the reverse of the negative and resembles the object in shading.

Photography is of great importance in everyday life. It is used for making some hundreds of thousands of miles of cinema film each year, and is specially useful in the study of astronomy, in surveying from the air, in printing processes, in surgery, and in the detection of criminals.

The preparation of chlorine

To prepare this gas the apparatus shown in Fig. 130 is erected in a fume cupboard. About 10 grm. of manganese dioxide are put into the flask and some concentrated hydrochloric acid run in from the tap-funnel. Little action takes place. The liquid is run round the flask till the sides are wet, then the flask is warmed. Chlorine is given off and collected by displacing air upwards. The colour of the gas shows when the jars are full. The equation for this reaction is :

$$MnO_2+4HCl \rightarrow MnCl_2+Cl_2+2H_2O.$$

The properties of chlorine

Chlorine is a greenish-yellow gas. It is poisonous, attacking the lining of nose, throat and lungs, so that it is advisable to smell the gas with caution. The odour reminds some people of decaying sea-weed, others of bleaching powder.

When chlorine is bubbled through water, it is found to be fairly soluble, and the solution, chlorine water, has much the same colour as the gas.

Chlorine is much denser than air. It does not burn in air, but a lighted taper or candle continues to burn in it with a red, smoky flame.

If a jar of chlorine is mixed with a jar of hydrogen in diffused daylight, little happens unless the gases are left together for a long time. In sunlight, the gases combine explosively, and ignition of the mixed gases by means of a taper is explosive; the product is hydrogen chloride:

$$H_2+Cl_2 \rightarrow 2HCl.$$

Chlorine combines with many metals, and if a piece of iron wire or thin copper foil is heated, then quickly lowered into a jar of the gas, the metal becomes red-hot as the two elements combine to form the metallic chloride. Iron gives ferric chloride, $FeCl_3$; copper usually forms brown copper chloride, $CuCl_2$.

Damp chlorine readily bleaches litmus paper, grass, ordinary ink but not printer's ink (carbon), i.e. the colour disappears and the paper or grass becomes almost white. The chlorine probably reacts with water to give hydrochloric and hypochlorous acids (HClO) thus:

$$Cl_2+H_2O \rightarrow HCl+HClO.$$

The hypochlorous acid readily loses its oxygen which is responsible for the bleaching.

If a jar of chlorine is opened under caustic soda solution, the gas dissolves readily. The reaction which takes place depends chiefly upon the temperature. If the caustic soda is cold, the products are sodium chloride and **sodium hypochlorite**, NaOCl; this substance is the active agent in the disinfectant "Milton." If the caustic soda is hot, chlorine reacts to form sodium chloride and **sodium chlorate**, $NaClO_3$. The latter substance is made on a large scale; it is used as a weed-killer for application to garden paths, and for conversion into potassium chlorate, $KClO_3$, which is used extensively in making matches.

When chlorine is passed over ordinary dry slaked lime, the substances react and the white solid product is called **bleaching powder** or incorrectly "chloride of lime."

Chlorine in quantity is easily detected by its colour and odour, but traces of the gas readily liberate brown iodine from a piece of filter paper which has been dipped in potassium iodide solution:

$$2KI+Cl_2 \rightarrow 2KCl+I_2.$$

The uses of chlorine

(1) A supply of drinking water free from disease germs is essential for good health; in many towns the water is treated

with very small quantities of chlorine gas. One part of chlorine in a million of water is sufficient to kill dangerous germs in a few minutes.

The water in modern swimming-baths is also sterilised by means of chlorine. The water is circulating continuously and is filtered, treated with chlorine, refiltered and warmed before it enters the bath again. In this way the water is kept clean, the risk of spreading disease is considerably reduced, and little water is wasted.

(2) Much chlorine is used in making bleaching powder with which cotton goods are bleached. The fabric to be bleached is first soaked in a dilute suspension of bleaching powder in water. Then it is dipped in a bath of dilute hydrochloric acid and it is at this stage that bleaching takes place. These operations can be easily followed by using litmus paper. Finally, the fabric is treated with a solution of an antichlor, i.e. a substance which takes up excess chlorine, after which it is washed.

(3) Chlorine is also used in the preparation of a number of chemical compounds which are employed in making dyes, flavours, etc. **Carbon tetrachloride,** CCl_4, which is about 92 per cent. chlorine is a colourless liquid ; it is used as a solvent and in fire-extinguishers on cars because it gives a dense vapour. **Chloroform,** $CHCl_3$, also contains a high percentage of chlorine and it is an important anæsthetic.

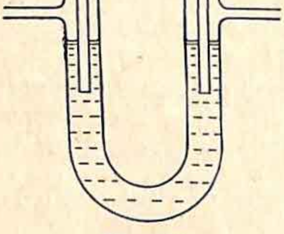


FIG. 133.

The electrolysis of salt solution

The effect of passing a direct current of electricity through a solution of common salt is illustrated simply by setting up the apparatus shown in Fig. 133. A solution of salt is made, a few drops of phenolphthalein solution added to it, then the mixture is poured into the U-tube. The carbon electrodes are fixed in position and a current of about 0·5 ampere is passed through the solution. The liquid becomes red at one electrode, which shows that an alkali is being formed ; the alkali is caustic soda. At the other pole a gas is evolved which liberates iodine from a potassium iodide paper ; the gas is chlorine.

By using a special kind of cell in which the two electrodes are separated by a porous partition, the electrolysis of salt solution is used to manufacture both caustic soda and chlorine.

The properties of caustic soda (sodium hydroxide)

This substance is a white solid which readily becomes wet on exposure to the air ; it takes up moisture from the air. Caustic soda is very soluble in water and during solution heat is evolved. Even dilute solutions of caustic soda feel slimy because the substance attacks the skin. Red litmus solution becomes blue when caustic soda is added to it. When acids are neutralised by the addition of caustic soda, the corresponding sodium salts are formed.

Solutions of caustic soda if left in contact with paint or varnish attack these substances. Caustic soda is made on a large scale chiefly for making soap.

EXPT. 4.—*Preparation of soap.*

Pour 10 c.c. methylated spirits into a boiling-tube and add 3 c.c. water. Next add 1 grm. solid caustic soda and stir with a glass rod till the solid dissolves. Warm this alcoholic solution of caustic soda in a beaker of hot water and add, in small portions, 4 grm. of lard. After each addition of the fat stir well with the glass rod. Finally, leave the boiling-tube in the hot water for a few minutes. The fat will react with the caustic soda and a clear brownish liquid is formed.

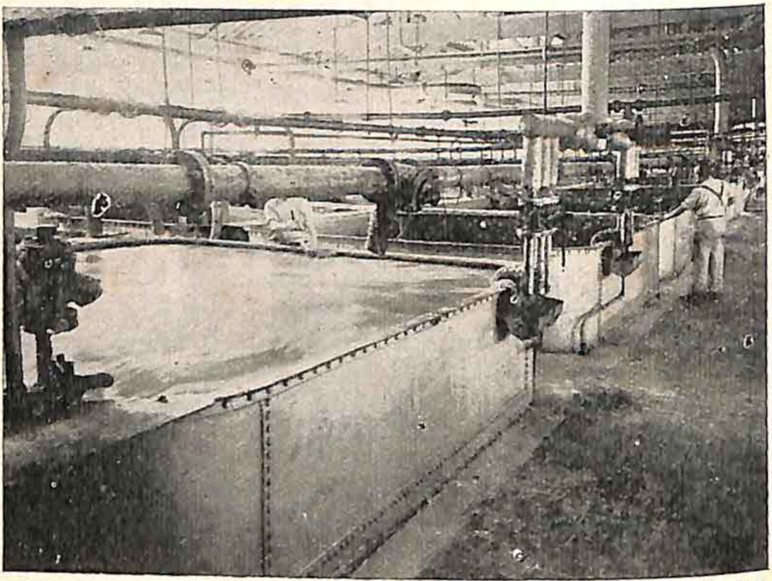
Next pour a few drops of the brown solution into a test-tube half full of water and shake. A good lather will be obtained. Pour the remainder of the brown solution into a saturated solution of salt. A whitish curdy substance separates ; this is soap.

Soap

Hard soaps are sodium salts of complex organic acids. They are made by the action of caustic soda on various animal and vegetable fats and oils, e.g. tallow, hardened whale oil, palm oil or olive oil. The reaction which takes place is summarised thus :

Fat+Caustic soda→Soap+Glycerine.

In manufacturing soap, the oils and fats are heated, then blended according to the quality of soap which is to be made. The hot oil is run into a large square pan which contains perforated steam pipes. Steam is blown into the oil, then caustic soda solution is added. The steam heats and stirs the mixture, and the alkali reacts with the fat as indicated above. Salt is shovelled into the pan, and, on standing, the soap separates on top. The glycerine and salt solution is run off from the bottom of the pan.



[*Photo : Lever Brothers, Ltd.*

SOAP BOILING.

Soap at this stage looks rather like treacle. It is often mixed with perfume and colouring matter, then run into large rectangular steel boxes till it sets solid. The sides of the boxes are then removed and the blocks of soap are cut first into slabs, then into bars. This type of soap is used for general washing and cleaning purposes.

Toilet soap is made from a blend of good fats or oils. After making the soap, as indicated above, it is cut into shavings, dried, mixed with colouring matter and perfume, and forced through a machine which gives a stick of soap. This stick is cut into convenient pieces which are stamped into tablets.

The function of soap in washing

Soap reacts with the substances dissolved in tap water producing a scum. It then dissolves in the water, and the soap solution is able to wet a surface better than water. The soap solution also causes oily or fatty matter on the skin to form an emulsion, i.e. a suspension of tiny droplets. When this emulsion is swilled off, the surface of the skin is left clean.

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CHAPTER 15

SOME IMPORTANT METALS AND THEIR USES

In Book I, p. 127, we learnt that the chemical elements can be divided into two main groups, viz. metals and non-metals. Most metals can be recognised by their physical properties, e.g. they are lustrous, have a high density, are good conductors of heat and electricity, and they are malleable and ductile. A better classification is based on their chemical properties ; thus a metal is an element which (1) has a basic oxide, i.e. an oxide which reacts with acids to form salts and water, (2) has a chloride which does not react with water, and (3) usually reacts with dilute acids, replacing the hydrogen of the acid to form a salt.

We are all familiar with the common metals iron, zinc, copper, lead, aluminium and tin, and have some acquaintance with valuable metals like gold, platinum and silver. But there are several other metals which are of great importance, e.g. chromium, tungsten, nickel, manganese.

Man has been in existence for several hundred thousand years, but for most of this time he lived in a primitive manner. He knew how to make tools and weapons, but originally he used wood, bone, flints and stone for this purpose. Not many metals occur free in nature ; copper is such a metal, but alone it is too soft for making tools. Eventually, man learnt how to make and use fire. With the help of fire, he found how to obtain tin from its oxide, which occurs naturally, and he discovered how to make an alloy of copper and tin, viz. bronze. This discovery gave man a substance from which he could make better tools and weapons. Then man learnt how to obtain iron, and this metal displaced bronze. Nowadays, iron is produced to the extent of some 80 million tons a year, chiefly for conversion into steel.

Iron

The extraction of pig or cast-iron was dealt with in Book II, p. 184. This kind of iron is rather impure and contains 3–4 per cent. of carbon ; it is brittle and cannot be forged, and it will not stand strain or shock. Cast iron is used for making pipes, railings, stoves, the metal parts of desks, bedsteads, etc., but the bulk of it is converted into steel.

Steel

Steel is a mixture of iron with a compound of iron and carbon (iron carbide), the carbon content varying up to 1·5 per cent. Different processes are employed for making steel ; in the Bessemer process, molten pig-iron is run into the converter (Fig. 134), tilted on its side, then air is blown through holes at the bottom of the converter while it is in the upright position. The air burns away most of the carbon and oxidises other impurities which are then taken up by the substance lining the converter. By adding alloys of iron with metals like tungsten, manganese, etc., special steels are made.

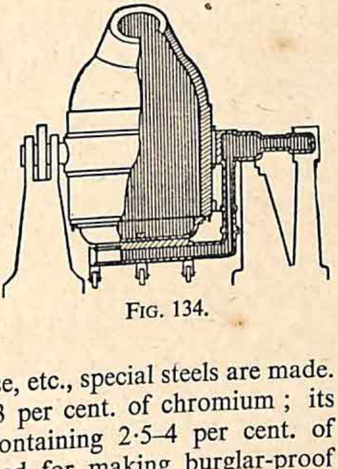


FIG. 134.

Stainless steel contains about 13 per cent. of chromium ; its uses are well known. A steel containing 2·5–4 per cent. of chromium is very hard ; it is used for making burglar-proof safes and railway couplings.

Chromium nickel steels are very tough ; they are made into armour plates for ships. Chromium tungsten steels retain their hardness at high temperatures ; they are used for planing down castings in engineering shops. A steel containing 12 per cent. of manganese is very hard and tough ; it is used for railway points and crossings, and for wagon-buffers.

Zinc

The extraction of this metal was considered in Book II, p. 186. A good deal of zinc is used for **galvanising** iron. The iron to be galvanised is first freed from rust by cleaning with an acid ; it is next dipped in a flux, e.g. ammonium chloride solution, then immersed in molten zinc. In this way the iron becomes coated with zinc and rusting is prevented.

Zinc is also required for making cells for dry batteries ; it is used as a substitute for lead for roofing purposes, and with copper it is made into the alloy called **brass.**

Copper

The extraction of copper from its ores is too difficult for us to treat in an elementary course. The metal is, however, one of considerable importance. Being a very good conductor of electricity it is used extensively in electrical industries. Since it is a good conductor of heat, it is used in making the fireboxes of locomotive boilers.

Copper is a constituent of several important alloys, e.g. brass and **bronze** (copper and tin). It is used a good deal in making coins ; our copper coins contain 95 per cent. copper, silver coins 40 per cent. copper, and gold coins 8–10 per cent. copper.

Lead

The production of lead from galena, PbS, is not an easy process. Lead is rather a useful metal since it is easily worked, bent and soldered. It is made into pipes for carrying water, and sheaths for electric cables ; it is used for roofing purposes and for making accumulator plates. Lead is also a constituent of important alloys, e.g. with antimony it gives **type metal**, an alloy which expands on cooling ; with tin it produces **solder** and **pewter.**

Aluminium

This metal has become one of considerable importance since the method of making it electrolytically was introduced. Pure aluminium oxide, Al_2O_3, is first made from the mineral *bauxite*. The oxide is dissolved in another mineral, *cryolite*, which is kept molten electrically in special cells (Fig. 135). Each cell consists of an iron box lined with carbon ; this box is the negative pole or electrode. The positive pole consists of a set of carbon blocks, which dip into the cryolite and aluminium oxide solution. During the electrolysis, aluminium is set free at the negative pole; the liquid metal collects at the bottom of the cell, from which it is "tapped" at intervals. Oxygen is liberated at the positive pole and the carbon blocks burn away so that they have to be replaced.

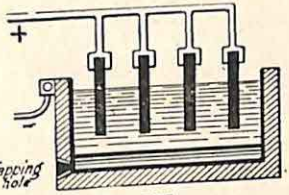


FIG. 135.

Because of their low density, aluminium and its alloys, e.g. **duralumin** and **magnalium**, are used in the construction of aircraft and parts of motors. Being a good conductor of electricity, aluminium is used for overhead transmission wires. Since aluminium is not easily corroded, it is made into cooking utensils, but these should not be cleaned with soda which attacks the metal. In the form of foil, aluminium is used for wrapping tea, sweets and cigarettes. The panelling and roofing of buses often consists of sheet aluminium, while the powdered metal is made into paint.

CHAPTER 16

INSECTS

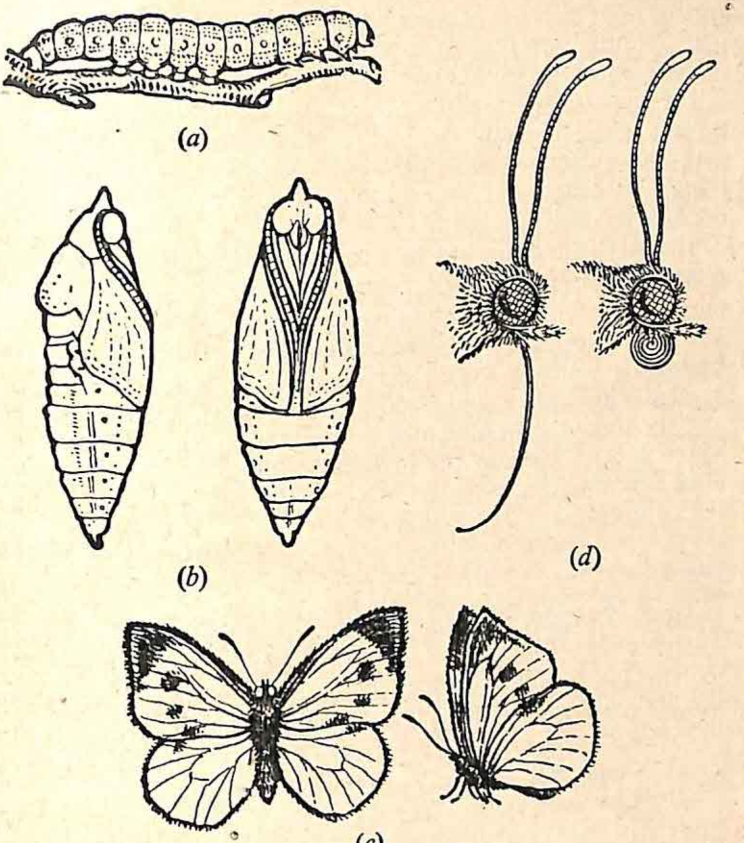
Arthropods

Many animals are boneless, e.g. fly, worm, starfish, snail. Some of these have a body divided into segments, jointed legs and an outer armour to protect the soft inner parts. Such animals are called **Arthropods**. The group contains the crustaceans (e.g. shrimps, lobsters), centipedes, millipedes, spiders and the most numerous of all animal classes, the insects.

A typical insect: the cabbage white butterfly

We can observe all the stages of this insect by collecting in May cabbage leaves with batches of yellowish eggs on the underside. The stems are immersed in a beaker of water and covered with a case, which has glass sides for the purpose of observation. About a week after they have been laid the eggs hatch, and fresh leaves should be supplied.

The young caterpillar feeds greedily and grows quickly, particularly following a moult, when the whole outer case is shed. There are several moults, since little growth can occur when the outer case has hardened. The caterpillar becomes fully grown in about two months. The animal (Fig. 136) has a head with hard biting and chewing parts, two short antennæ (feelers), six minute eye spots (visible only through a lens), and the spinneret, a projection from the silk gland. The rest of the body is in thirteen segments, three forming the thorax and ten the abdomen. It is greenish, with black spots, and has along the back a yellow stripe in which a lens reveals tiny breathing holes, the spiracles. These conduct air by a series of breathing tubes, the tracheæ, to all parts of the interior. The three thoracic segments each carry a pair of short jointed legs; four


(a)

(b)

(d)

(c)

FIG. 136.—CABBAGE BUTTERFLY.

(a) larva; (b) pupa; (c) adult female; (d) head showing proboscis.

of the abdominal segments carry stumpy projections, the prolegs, while the last segment carries a pair of claspers.

When it is fully grown the caterpillar stops feeding and suspends itself by a silken thread from a twig or fence. It becomes short and fat, sheds its skin and turns into a pupa (or chrysalis). In this stage the insect appears dead except for an occasional wriggle, but marked changes are occurring in the organs, and features of the adult butterfly, or imago, become visible through the thin skin. When the changes are complete the butterfly emerges, expands and dries its wings, and flies away.

The pupal stage of insects hatched in May lasts for two or three weeks, the adults emerging in August and laying their eggs to give summer hatched caterpillars. The pupæ from these remain in a dormant stage through the winter, and the adults emerge in April.

The adult butterfly has two pairs of wings, the female being distinguished by three dark spots on each front wing. The antennæ are long, with club-like ends (distinction from moths). The insect feeds by imbibing nectar through a long tube, the proboscis, which is curled up when not in use. The body is divided into thorax and abdomen, like that of the caterpillar, and the three thoracic segments each have a pair of jointed legs. There are no legs on the abdomen. Like the caterpillar, the adult has spiracles, a feature which is characteristic of insects in the adult form.

Insects

There are more than half a million different *kinds* of insects. This is more than all the other kinds of animals together. The class includes butterflies and moths, bees, wasps, ants, beetles, the housefly and gnats (mosquitoes). The characteristics of insects are—

(1) A body divided into head, thorax and abdomen ;
(2) Three pairs of legs on the thorax ;
(3) One pair of antennæ ;
(4) Spiracles and tracheæ.

The adult butterfly shows all these features.

Many insects have life-histories similar to the butterfly. The young, growing stage is known as the **larva**, the resting stage as the **pupa** and the adult as the **imago** or perfect insect.

Fleas

Fleas form a class of insect in which there are over 500 kinds. Forty-six of these occur in Britain. The human flea (*Pulex irritans*) is probably chiefly celebrated for its jumping ability, but biologically its most marked characters are its piercing and sucking organs, and its shape. The insect is very narrow, thus enabling it to pass easily between the hairs on its host.

The flea is a parasite, living on the blood of its victim. To feed, it bores a hole and enlarges it by a sawing motion, saliva dribbling down into the wound. Blood is then sucked up by a pumping action of the flea's pharynx. The irritation which follows is due to yeasts which enter the wound and are not completely reabsorbed.

Fleas are specialists to a limited extent as regards the host on which they are parasitic. Thus a dog flea is not the same as a human flea, but this specialisation does not altogether keep the parasite to its own kind of host.

Life history of fleas

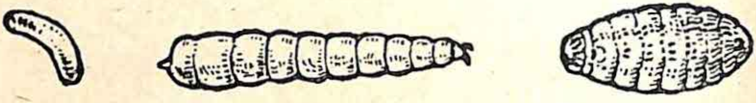
The human flea lays its whitish oval eggs in dirt and floor debris. The larva is a limbless maggot which forms a pupa after two moults. In the pupal stage it may last from a week to a whole winter. The adult has a small stomach, and feeds at least twice a day, but can survive from one to four months without food. Feeding prolongs its life to eighteen months.

When the host of a flea dies, the flea leaves the body after it cools down. This feature is of importance in the spreading of flea-borne disease.

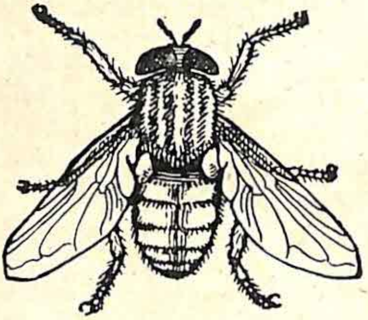
The house-fly

The house-fly is probably the best known of all insects. Its creamy-white spindle-shaped eggs (Fig. 137) are laid in manure, bad meat and other decaying material. After about 24 hours they hatch, forming legless segmented larvæ (maggots or "gentles") which move by wriggling and feed on the surrounding material. In less than a week the larvæ moult twice and grow to ten times their original size. They then seek dry crevices in order to pupate. The shape becomes oval, the skin brown and they turn into pupæ without a further moult. A few days later colourless young flies emerge, their wings expand and harden, their bodies darken and they fly off, to breed in another ten days or so. Adult flies do not grow, and in summer may live only a few weeks, during which a female may lay up to 800 eggs. A few hibernate until spring and so perpetuate the race.

In its general construction the house-fly has much in common with the butterfly but only the front pair of wings function in propelling the insect. The back wings form small club-shaped structures which are believed to help as balancers in flight.



(*a*) egg (*b*) maggot (*c*) pupa



(*d*) adult

FIG. 137.—HOUSE-FLY.

Insects and disease

Although it is convenient to study the different kinds of living things separately, we must appreciate that one kind of animal or plant may play an important part in the life of another. Many flowers depend on insects to effect pollination (p. 208), and insects concern human beings as carriers of disease or ravagers of useful crops.

The great plague, which swept London and killed 25 million people in Europe, was spread by rat fleas. Fleas often carry disease bacteria in their intestines. The fleas migrate to human hosts when their original hosts are killed by the infection. The bacteria enter the human body when the fleas bite, and through skin abrasions caused by rubbing.

The house-fly spreads disease in several ways. When a fly visits a solid food material it secretes enzymes which dissolve the food, and then sucks back the solution. The enzymes may be mixed with partially digested food from the fly's previous meal, possibly at a nearby manure or rubbish heap. The fly's feet carry dirt from the same place, and while feeding it may shed fæces (p. 51). Thus flies convey germs, some of which may be disease-producing types, to our food.

It is clear that many diseases can be prevented by killing insects, or by not allowing them to breed in or near the house. Fleas can be checked by killing rats and by keeping pets clean. Protection against flies is best achieved by eliminating breeding places near the house, and by covering food. Malaria, which is spread by mosquitoes, is kept in check by draining swampy grounds and spraying stagnant water with oil to kill the larvæ, and by protecting human beings by mosquito nets.

CHAPTER 17

FLOWERS, FRUITS AND SEEDS

The structure of flowers

The wallflower (Book I) can be used to illustrate the general construction of a flower, although the details apply only to the wallflower itself. Fig. 138 represents a section through the flower with the parts spread out to show them more clearly.

The various parts of the flower grow on the **receptacle**. The outermost ring, or whorl of purplish-green **sepals** is called the **calyx**. The next whorl, the **corolla**, consists of coloured **petals** and inside this again are the **stamens**, two of which are surrounded at their bases by the **nectaries**. Each stamen has a stalk, the **filament**, bearing a lobe, the **anther**, in which the **pollen** grains develop. The innermost portion of the flower consists of **carpels**. In the wallflower these are joined together at their bases to form the **ovary**, and in the middle to form the **style** which acts as a support for their upper parts, the **stigma**. When the carpels are joined together the united structure is sometimes called the **pistil**.

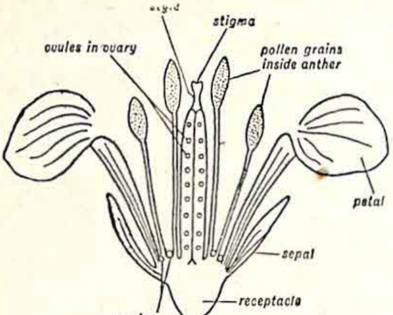


FIG. 138.

Pollination

Pollination is the transfer of pollen from the anthers to the stigma, and must occur before the ovules can be fertilised and form seeds. When the process takes place within one flower it is called **self-pollination**, but when pollen is transferred from one flower to another the term **cross-pollination** is used. Cross-pollination allows the production of new varieties of plant which combine characteristics from the two plants involved. Self-pollination, on the other hand, allows desirable characteristics to be preserved without alteration. Cross-pollination seems the more usual method, some plants actually having devices which prevent self-pollination. In other cases self-pollination takes place only if cross-pollination fails.

Pollen grains may be carried by the wind or by insects such as bees; for the purpose of transfer to a second flower a plant usually adopts *one* of these two methods.

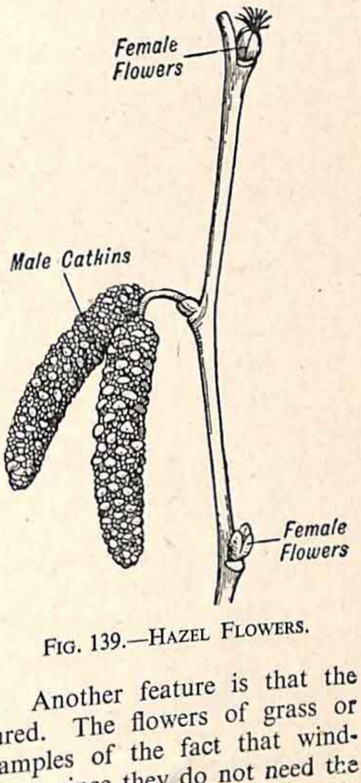


FIG. 139.—HAZEL FLOWERS.

Wind-pollination

Poplar, hazel and other catkin-bearing trees except the willow are well known examples of plants whose flowers are wind-pollinated. The *large quantity of pollen* which they produce is needed in order that the stigmas, which are on separate flowers (Fig. 139), may be certain of pollination. Another feature is that the flowers are not brightly coloured. The flowers of grass or the oak are perhaps better examples of the fact that wind-pollinated flowers are *inconspicuous*, since they do not need the visits of insects. For the same reason, *no nectar* or *scent* is produced. The trees also produce *flowers before leaves* in order to avoid hindrance to the spread of pollen. The pollen grains themselves are *very light* and easily wind borne, and the *stigmas* are *spreading and feathery*, so that pollen adheres easily.

Pollination by insects

The wallflower is usually pollinated by insects. Bees use the *scent* and *colour* of flowers as a guide to direction. It is thought that in many cases they can see colours at a considerable distance. An Austrian biologist trained bees to visit a dish of sugar solution which he always placed on a piece of blue paper surrounded by papers of other colours. When he repeated his experiments but removed the dish of sugar solution, the bees again flew to the piece of blue paper and searched there for the food. Flowers are visited for the *nectar*, a sugary solution which the bees use to make honey to serve as a food store for the hive. In the search for nectar, pollen is rubbed off the anthers on to some part of the insect's body (the head when a bee visits a wallflower). It is transferred thence to the stigmas of flowers which the insect subsequently visits. Bees also collect pollen as food, but on the whole there is a *smaller production of pollen* than in wind-pollinated plants, since less is wasted by indiscriminate scattering.

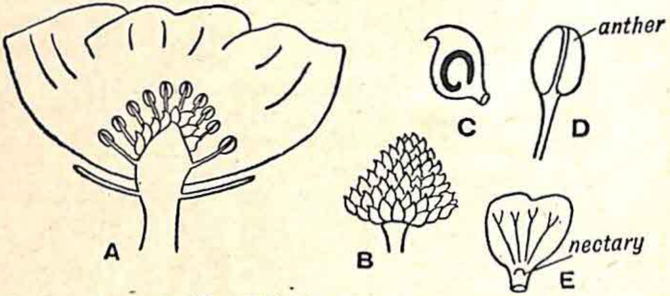


FIG. 140.—BUTTERCUP.

A, section through flower ; B, the carpels ; C, section through a carpel ; D, stamen ; E, petal.

Cross-pollination

In the **buttercup** (Fig. 140) the nectaries are at the bases of the petals. When the flower opens, the anthers ripen, starting with the outer ones and gradually progressing inwards. The stigmas are not yet ripe, so that an insect gets pollen on its body, but cannot transfer it to the stigmas. If the insect visits a flower in a later stage of development, the stigmas have ripened and are touched and pollinated by pollen from the underside of the insect's body. The ripening of the male and female parts in the

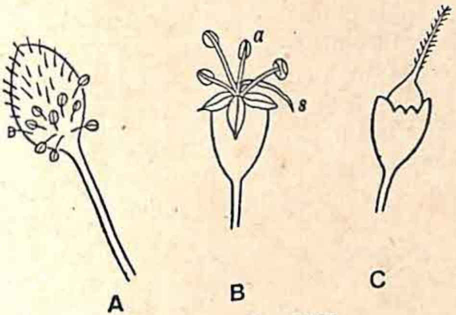
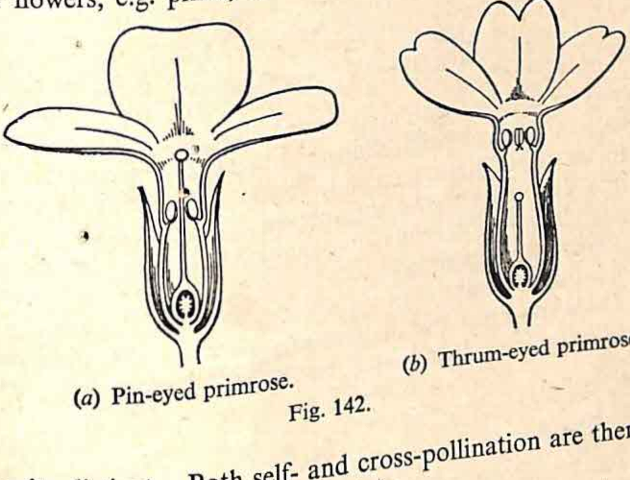


FIG. 141.—PLANTAIN.

A, spike with young and old flowers ; B, old flower with stamens (*a*) and withered stigma (*s*) ; C, young flower with exposed stigma.

buttercup are not completely separated in time, and the inner anthers still have pollen when the stamens are ripe. In some other flowers, e.g. pinks, the times of ripening of the two parts



(*a*) Pin-eyed primrose.

(*b*) Thrum-eyed primrose.

Fig. 142.

are quite distinct. Both self- and cross-pollination are therefore possible in buttercups but not in pinks.

In other flowers, e.g. the **plantain** (Fig. 141), which is wind-were the last to ripen, and still contain pollen, so that self-pollination occurs. Similarly, in the wallflower, self-pollination is effected when cross-pollination has not taken place. In this case, however, the long stamens bend over and drop their pollen on to the stigma.

Some kinds of flowers, e.g. the garden pea, are almost always self-pollinated. Some gardeners save their best pods for seed year after year, and preserve a strain of peas without alteration in character. Wheat flowers and many wild flowers are self-pollinated.

Fertilisation

When a pollen grain alights on the stigma, the pollen cell puts out a tubular growth, the **pollen tube,** which makes its way downwards (Fig. 144) and penetrates an ovule. The pollen tube produces two nuclei which act as male gametes. Fertilisation is brought about by fusion of one of these with a portion of the ovule. This produces a zygote which divides and subdivides until it forms a young embryo (radicle+plumule+one or two cotyledons). In many flowers fusion of the second male gamete with further portions of the ovule stimulates production of the **endosperm,** a structure which supplies food to the embryo. At a certain stage, development of the embryo and its surrounding tissues ceases, and the resulting **seed** remains dormant until it encounters conditions suitable for germination (Book II., p. 35).

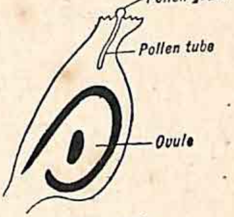


FIG. 144.

Development of the ovary wall also follows fertilisation, and a protective cover is formed for the seed in addition to the seed coat produced by the seed itself. For a length of time which varies in different plants the seed remains within this outer cover, forming the structure known as a **fruit.**

Fruits

There is a wide variety of forms into which the ovule and ovary develop in fruit formation. The nature of these forms influences the ways in which the seeds are spread, and an idea of their pollinated, the stigmas ripen before the stamens. The upper flowers in the head are the younger ones, and these show a long stigma with undeveloped stamens while the older flowers at the base have withered stigmas and ripe stamens. Self-pollination is therefore possible but it is more likely that the upper stigmas will receive pollen from a separate head of flowers.

Primroses are of two kinds, thrum-eyed and pin-eyed (Fig. 142). The nectary in both is at the bottom of the long tube formed by the petals, and a bee in search of its food becomes dusted with pollen. In the pin-eyed flower the insect's proboscis becomes coated ; in the thrum-eyed flower pollen is dusted on to the insect's head. If the insect later visits another flower with a stigma at the same height as the anthers from which the pollen came, cross-pollination is effected. Self-pollination is also possible, especially in the thrum-eyed flower. Cowslips and the garden flower, polyanthus or primula, show the same features as primroses in this respect.

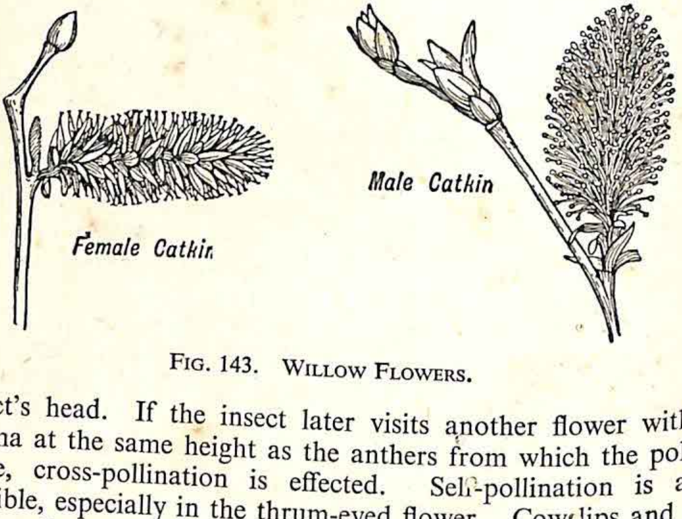


FIG. 143. WILLOW FLOWERS.

A particular willow tree produces flowers of one sex only (Fig. 143), so cross-pollination must occur. Oak tree flowers are either male or female, but the two kinds occur on the same tree.

Self-pollination

In the buttercup, when cross-pollination does not occur, the stigmas curl outwards and touch the nearest anthers. These

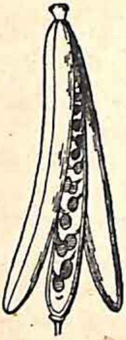


FIG. 145.—SILIQUA OF WALLFLOWER.

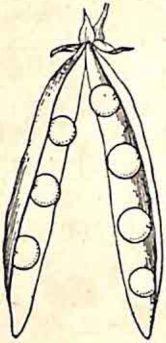


FIG. 146.—PEAS IN POD.

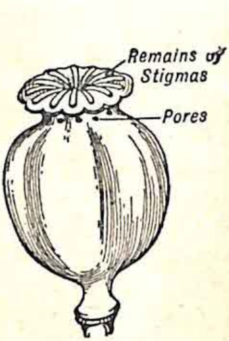

Remains of
Stigmas
Pores

FIG. 147.—POPPY CAPSULE.

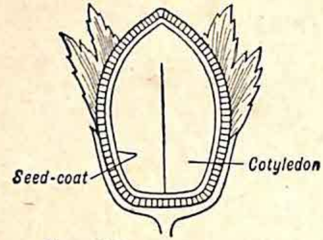

Seed-coat
Cotyledon

FIG. 148.—HAZEL NUT.

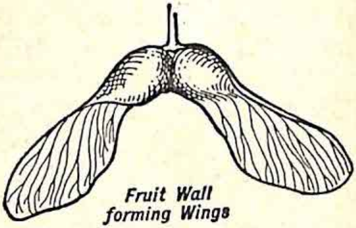

Fruit Wall
forming Wings

FIG. 149.—SYCAMORE FRUITS.

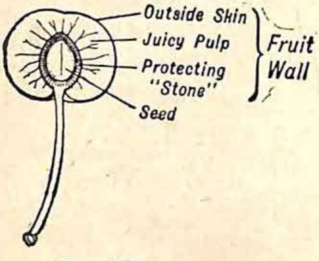

Outside Skin
Juicy Pulp
Protecting "Stone"
Seed
Fruit Wall

FIG. 150.—CHERRY.

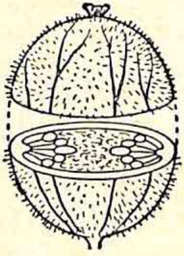


FIG. 151.—GOOSEBERRY.

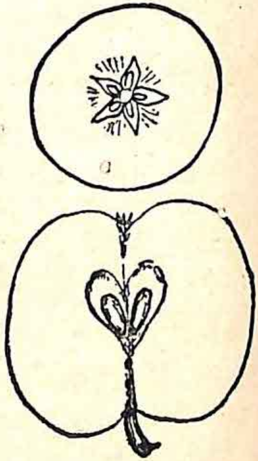


FIG. 152.—APPLE.

variety is given by the following simplified table in which fruits are classified according to structure (Figs. 145 to 154).

DRY FRUITS

BOX FRUITS. Open when ripe to allow escape of seeds.	1. Siliqua. 2. Pod. 3. Capsule.	Wallflower. Pea, gorse, broom. Poppy, pansy.
NON-SPLITTING FRUITS. Contain a single seed which does not escape.	1. Achenes (nutlets) : small. 2. Nuts : large, with woody fruit case. Kernel is the seed.	Sunflower. Hazel.
COMPOUND FRUITS. Divide when ripe into separate "fruitlets," each containing a single seed.		Sycamore. Nasturtium.

JUICY FRUITS

STONE FRUITS (drupes). The seed is the kernel. Stone, juicy part and skin formed from ovary wall.	Cherry, plum.
STONELESS FRUITS (true berries). Skin and pulp formed from ovary. Seeds embedded in the pulp.	Gooseberry, currant, tomato.
Less obvious cases. *Pomes:* fleshy part derived from receptacle instead of ovary (formerly called false fruits).	Apple, pear.
Compound fruits. 1. Collection of achenes. 2. Collection of drupes.	Strawberry (achenes embedded in receptacle) ; buttercup. Blackberry, raspberry.

Seed Dispersal

Gardeners "thin out" seedlings which are overcrowded, and discard or transplant the uprooted ones. The remainder have freer access to air and soil and have better access to food-making material and sunlight.

Overcrowding also affects plants in natural conditions, since many of them produce seed prolifically. A new kind of wheat, of which a single ear was grown in 1903, covered 30,000 square miles of Canada in 1918 and yielded 8 million tons of grain, all descended from the single ear of 1903. The seed was spread by man, but many plants have special devices for the purpose. If the seeds fell straight to earth the seedlings would be in fierce competition with each other and (in many cases) with the well-established parent plant, both for soil-water and for air and light. Dispersal of seeds over a wider area ensures that a few shall propagate, even if many fall in unsuitable spots.

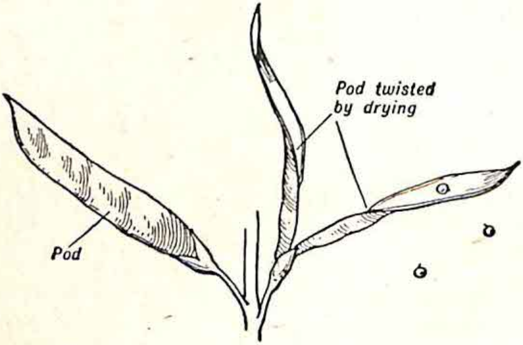


FIG. 153.—EXPLOSION OF BROOM POD.

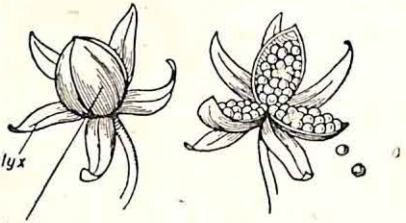


FIG. 154.—CAPSULE OF PANSY.

Plants show very varied devices which ensure scattering of seeds or fruits. In some cases the plant itself makes provision for the dispersal. In others the devices ensure that wind, animals or water shall help in the process. We must not, of, course, assume that the plant has in any way "thought out" these devices. Rather they must have arisen by chance, and

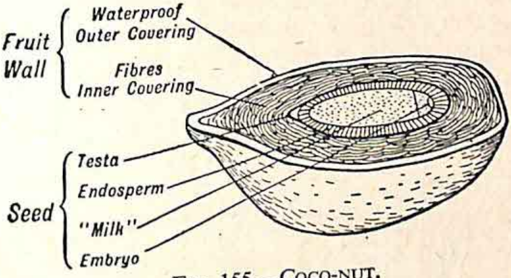


FIG. 155.—COCO-NUT.

then have helped their possessors to success in the continual competition for breeding space.

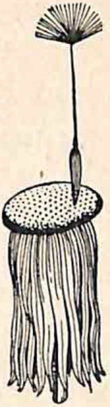


FIG. 156.—DANDELION PARACHUTE.

Self-dispersal is effected by many box fruits. Broom pods tend to uneven shrinkage as they dry, but are held in place at their edges. Suddenly the strain tears apart the two halves, the fruit explodes with an audible "pop," and the separate halves curve into spirals (Fig. 153) and throw out the seeds, often to a distance of several feet. Pansy capsules open suddenly and eject the seeds (Fig. 154) while poppies shake their seeds through pores in the capsule, a pepper-box effect which is aided by wind or the passage of animals.

Dispersal by water is frequent in rushes and pondweeds. Seeds or fruits of these are often made buoyant by air cavities. The thick fibrous outer layers of the coco-nut (Fig. 155) have the same effect, and it is thought that trees growing on the muddy banks of streams may have originated from water-borne nuts

Wind dispersal occurs with very light seeds, such as those of orchids. Dandelion (Fig. 156) or thistle fruits, and willow-herb seeds (Fig. 157) have tufts of hairs which give a parachute-like effect, while heavier fruits such as those of ash, sycamore

(Fig. 149) or lime have wings which enable them to be carried for moderate distances by the wind.

Dispersal by animals occurs in two ways. Many fruits, such as avens (Fig. 158), goosegrass or burdock, have small hooks which catch in the fur of animals, or in the feathers of birds. The fruits may travel big distances before they are rubbed off.

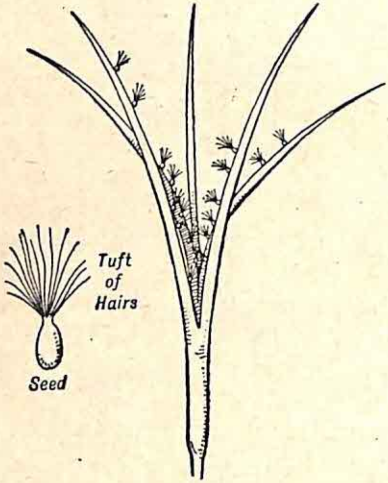


FIG. 157.—WILLOW-HERB.

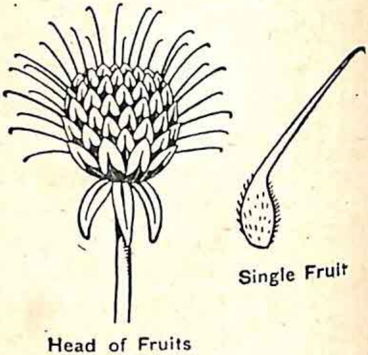


FIG. 158.—AVENS.

Other fruits or seeds may stick to mud on an animal's foot and be transferred in this way. Thrushes spread mistletoe seeds by their beaks (p. 75).

In many juicy or fleshy fruits which are eaten by birds or other animals the seeds have coats which resist the action of digestive juices, and are therefore likely to be dropped at a distance from the parent plant. The bright colour of many such fruits, e.g. haws, cherries, plums, rose hips, attracts the attention of birds and so helps in the dispersal.

CHAPTER 18

HEREDITY AND EVOLUTION

Heredity

We should be very surprised if we obtained a set of lettuce plants after setting some seed peas. We should be even more surprised if our domestic cat had a litter of young pigs. In fact either occurrence would create widespread interest well outside our own family circle. It would be such a great breach of the general rule " Like begets like."

It is frequently said that someone " takes after " his or her father or mother, implying that there is a fairly marked resemblance. Moreover, children of the same parents resemble each other much more closely than unrelated children chosen at random.

The rule " Like begets like," the resemblance of offspring to their parents, and consequently of related offspring to each other are results of **heredity** which is a very widespread phenomenon, and extends through the animal and plant kingdoms.

Variation

Like does not beget like exactly. Brothers and sisters do not in general resemble each other exactly. Their hair colour may be different, and even if this is not so, minor details are certain to show a degree of diversity. An oak tree is never identical with the oak which produced the acorn, and the phrase, " like as two peas in a pod " is manifestly untrue when the peas are closely examined. Clearly then there are **variations**. The resemblances of heredity are incomplete, and we must examine the differences with a view to ascertaining their origins.

(1) Two children of the same parents, fed and treated as nearly alike as possible, may differ considerably. One may have dark hair and brown eyes while the other may have light

hair and blue eyes. These differences are due, not to differences in environment but to differences in inheritance. Since strains of organisms are often not pure (p. 220) many variations turn up in this manner.

(2) Even in a pure strain, we still have variations, e.g. in size. These are due to differences of environment such as the position of the bean in the pod, or of the pod on the plant, a shady or sunny situation. Biologists on the whole do not believe that differences of this sort have any hereditary effect. If one of two brothers, sun-tanned by residence in Africa, has children, they are not noticeably darker at birth than the children of the brother who has remained in England.

(3) The two preceding causes account for most, but not all variations between parent and offspring. A third cause is known. Sometimes a kind of plant or animal which has bred for generations without alteration of character, suddenly produces offspring with some noticeable change. Red Shirley poppies may produce seeds which give rise to plants with flowers of a different colour. A pure breed of normal sheep once produced a ram whose legs were so short it could not get out of a field with even very low fences. When such sudden changes occur breeders call the new form a sport. Biologists describe it as a **mutation.** It is important to note that the change is a *sudden* one, and that it *is inheritable*, so that an entirely new character is transmitted to the offspring. Many such examples are known, but it must not be imagined that the changes are always as marked as the two just mentioned. It is naturally the most striking mutations which are easily noticed.

The gametes and heredity

Flowering plants reproduce by seeds. A seed is formed after the fertilisation of a female gamete in the ovule by a male gamete from the pollen cell. Similarly many animals begin development after the fertilisation of a female gamete (ovum, egg cell) by a male gamete (sperm cell). In most organisms the gametes are the only link between the parents and their offspring. Even in mammals, whose young are mostly born alive, it has been shown that the link between parent and offspring is almost entirely by means of the gametes.

The term **hereditary factor**, or **gene**, is usually employed to denote whatever it is which passes from parent to offspring and determines a particular characteristic in the latter. From what we have just seen, it follows that these factors must be carried in the gametes.

The chromosomes

When a living cell is about to divide into two, a number of rod-like objects, the **chromosomes** (Fig. 159) become visible in the nucleus. The chromosomes are composed of even smaller structures, the actual hereditary factors. In the bodies of individuals of a given species *all the cells* except the gametes *have the same number of chromosomes, which are arranged in pairs*. Man has 48 chromosomes (24 pairs) per cell. It is the constancy of this number which is important, not its actual value. The number in an onion cell is the same as that in the cell of an ox or a guinea pig.

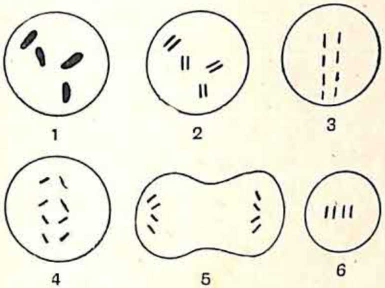


FIG. 159.—1 TO 6: CELL WITH CHROMOSOMES UNDERGOING ORDINARY CELL DIVISION

FIG. 160.—GAMETE WITH HALF NUMBER OF CHROMOSOMES.

In ordinary cell division each chromosome splits lengthwise into two, and each new cell receives the full number of half chromosomes which then develop into full ones. The two new cells each have the same number of hereditary factors as the original cell.

By contrast with this, gametes are formed in such a way that chromosomes are *shared*, not split. As a result *each gamete contains only a half number of chromosomes, i.e. one set* (Fig. 160).

but the union of gametes in the act of fertilisation restores the full number to the resulting zygote. Each parent thus contributes equally, by means of the factors in the gametes, to the character of the offspring, despite the fact that the egg cell may be many times larger than the sperm.

The two packs of cards

Every organism receives a complete set of hereditary factors from one parent, via the male gamete, and another set from the other parent, via the female gamete. It is as if these two sets were each a complete pack of cards. The individual then has two of every card in the pack. For example, there would be one factor for eye colour from each parent. Thus, for determining eye colour an individual may receive one factor for blue eyes and one factor for brown eyes. Will the result be an intermediate colour, or will it be just blue, or just brown? Again, what will happen when this individual has descendants? Will they remain a mixture of blue and brown, or will it be possible to get back blue separate from brown, or brown separate from blue?

Mendelism

Before we had any knowledge of hereditary factors, or even of chromosomes, an Austrian monk, Gregor Mendel, had discovered the laws which describe the results of heredity in peas. These laws, discovered by breeding experiments in his garden, apply also to such different organisms as man, rhubarb, guinea-pigs and nettles. The laws are almost universal in the plant and animal kingdom, and the name "Mendelism" has been given to them in honour of their discoverer. The cases which we are now going to consider were not investigated by Mendel, but serve as illustrations of his discoveries.

In human beings two blue-eyed parents always have blue-eyed children, and two brown-eyed parents, *provided that they have only a brown-eyed ancestry*, always have brown-eyed children. In both cases, the fact that all the children have the same eye colour as their parents shows that the parents are what is known as *pure for eye colour*.

On the other hand, if one parent is blue-eyed, and the other pure brown, all the children have brown eyes. If two such children marry and become parents, some of their children may be brown-eyed, but others may be blue, *showing that the factor for blue eyes must have been present in the brown-eyed parents.* These parents are therefore *hybrid for eye colour.* Since the brown-eyed factor overcomes the factor for blue eyes, causing the eyes with both factors to appear brown, brown is said to be **dominant** to blue, and blue to be **recessive** to brown.

Sometimes one factor is not dominant to the other. A black Andalusian hen mated with a white cock gives blue hybrids. The only essential difference here is that it is possible to recognise the hybrids at sight.

Mendel also showed that it was possible to predict the proportions of the different kinds of organisms produced, providing that they were in large enough numbers. This is not, of course, often possible in human heredity, since the numbers ot children are relatively small unless very large numbers of families are taken into consideration. The results when this is done are as follows :

(*a*) Pure blue × pure brown gives all hybrid brown-eyed children. (The sign " × " signifies " mated with.")

(*b*) Hybrid brown × hybrid brown gives 25 per cent. pure brown-eyed children, 50 per cent. hybrid brown and 25 per cent. pure blue.

(*c*) Pure blue × hybrid brown gives 50 per cent. pure blue and 50 per cent. hybrid brown.

An explanation of Mendelism

The discoveries of Mendel have been explained and extended by the knowledge of chromosomes and factors.

Let a capital B represent a dominant brown factor, and a small *b* represent a recessive blue factor. The " pure brown " parent has two sets of chromosomes, each set with the same eye colour factor, B. This can be represented as BB (Fig. 161). The blue-eyed parent similarly has the two blue factors, *bb*. Gametes from the brown-eyed parent have the single factor, B. Those from the blue-eyed parent have the single factor *b*. Fertilisation produces B*b*, a hybrid with one brown and one blue factor, but, owing to dominance, the hybrid *appears* the same as a pure brown.

When gametes are formed by the hybrid organism B*b*, the chromosomes are shared, giving gametes with the single factor B *or b*, but *not with both.* It also follows from the mechanism of gamete formation that B and *b* are in equal numbers. There will be as many male gametes B as male gametes *b*, and the numbers of female gametes B and *b* will also be equal. A male gamete B, finding and fertilising a female gamete will thus have an equal chance of forming offspring BB or B*b* (Fig. 162). Similarly a male gamete *b* has equal chances of forming offspring B*b* or *bb*. Provided that the total number of offspring is large enough their actual numbers will be in the same proportion as their chances of formation, which we have just seen are 1 BB (pure brown) : 2 B*b* (hybrid) : 1 *bb* (pure blue). This is the same as Mendel discovered by experiment.

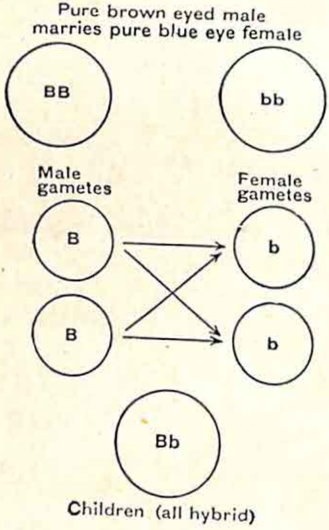

Pure brown eyed male
marries pure blue eye female
BB
bb
Male gametes
Female gametes
B
B
b
b
Bb
Children (all hybrid)

FIG. 161.

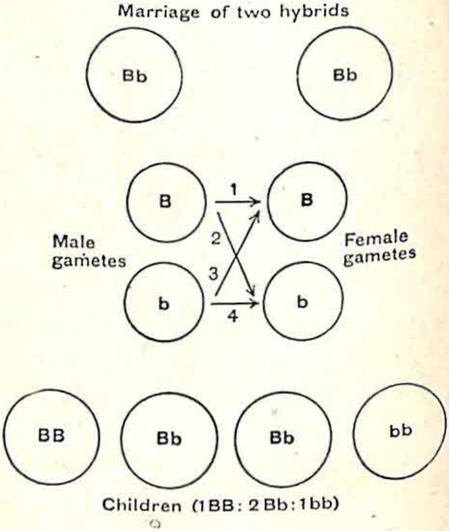

Marriage of two hybrids
Bb
Bb
B
B
1
2
3
4
Male gametes
Female gametes
b
b
BB
Bb
Bb
bb
Children (1BB: 2Bb: 1bb)

FIG. 162.

The same result can be obtained, often more conveniently, by arranging the possible male and female gametes, in the correct proportions, along two sides of a chequered square (Fig. 163), and completing the results of crossing in the small squares. As a very simple exercise on this you should determine the results of crossing a hybrid B*b* with one of the pure characters BB or *bb*.

We should note that many cases are not as simple as that we have just discussed. The colour of a man's skin, for example, is governed by at least three separate pairs of factors, while five (or more) pairs govern hair colour in rabbits. In such cases complete analysis of the factors needs a long investigation rather than a series of simple observations.

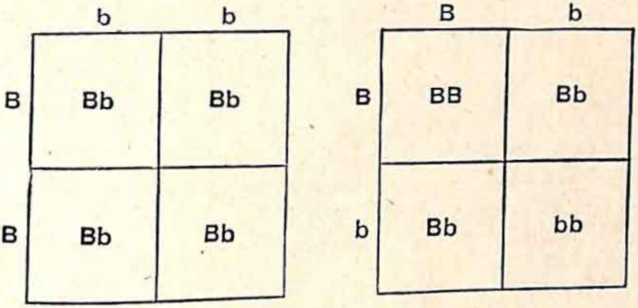


FIG. 163.

Boy or girl?

When the chromosomes of a cell are examined closely, it is found that they are in pairs, the two members of a pair being alike, with one exception. The males of most animals have one pair of odd chromosomes which differ in both size and shape. The smaller of these is known as the Y chromosome, and the larger as the X. In females on the other hand, this pair consists of like chromosomes, both members of the pair being of the X type. A male is therefore an animal with chromosome equipment XY (in addition to the other paired chromosomes), while a female is one with equipment XX. (In birds and butterflies the reverse is the case, XY being the female.)

This knowledge shows us that *the sex of an animal is determined by the male gamete at the moment of fertilisation.* All female gametes carry the X chromosome (Fig. 164). Half the male gametes carry the X chromosome, and half the Y chromosome. If one of the former fertilises the ovum, the result is XX, or female. If one of the Y-bearing sperms fertilises the ovum, the result is XY, or male. These considerations also suggest that there should be equal numbers of males and females produced. Since this is only approximately the case, other factors must play a minor part, one of these certainly being (in the case of man) the lesser resistance of the male to unfavourable conditions or disease.

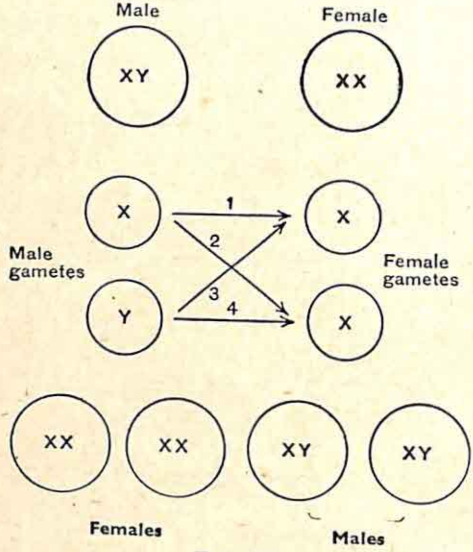


FIG. 164.

Practical applications of Mendelism

Knowledge gained in the study of heredity has been of immense importance to man in his breeding of plants and animals, particularly in the production of new and improved varieties of plants which provide food.

Previous to 1921 the sugar canes of Java were not satisfactory because they were susceptible to fungus diseases which often ruined the crops. In that year the special Dutch laboratory for plant research in Java produced a new variety with a high proportion of sugar, and capable of resisting the worst plant pests of Java. A simplified account of how this was done is as follows.

A good cropping sugar cane which was susceptible to disease was crossed with a wild cane which was resistant but contained practically no sugar. The resulting hybrids were all susceptible to disease, since resistance to disease is a recessive character. At this point the experiment might have been abandoned but for a knowledge of Mendelism. On crossing these hybrids the various factors were reshuffled so that in one of the resulting varieties the factors for resistance and high yield were combined. By 1926 the laboratory had produced sufficient of this new cane to begin large-scale cultivation, and since 1928, 95 per cent. of Java sugar canes have been of this type. Java increased her sugar output in the same time from a normal crop of 10,000 kilograms per hectare to about 16,000 kilograms per hectare, and rose to become the second largest sugar exporting country in the world.

In this country new and improved varieties of wheat have been produced by similar methods. By crossing a poor quality grain wheat which was resistant to yellow rust (the chief wheat pest in this country) with a good quality non-resistant type, an apparently useless hybrid was obtained. By self-fertilisation of these hybrids a number of different types was obtained, two of which, Little Joss and Yeoman, now occupy a very important position in English wheat production.

Mutations

The sudden change in a character which produces a sport or mutation is due to a sudden alteration in the corresponding hereditary factor, not to a mere rearrangement. We have no accurate knowledge of the methods by which many mutations have been brought about, but in a few cases they have been induced artificially by means of X-rays. We should note that the change which is produced is in the chromosomes of the reproductive cells, not in the ordinary body cells of the parent. This is an important distinction from the " acquired character " of Lamarck's theory (p. 231).

Inter-relations of living things

When man began to study living things his first observations were of their shapes and other features which we should call their external characters. Even at this stage, with no apparatus other than his eyes, he would see that things could be put into groups, such as plants and animals, and into sub-groups, such trees, or birds, or fishes. Some of these were so different, e.g. men and mushrooms, that there seemed no connection between one and the other, except that they were both living organisms.

When study progressed further, using simple apparatus such as a knife, more similarities were seen. Whole groups of animals had very similar body structures. Animals as different in appearance as man and a rabbit or bat, had a similarity in their skeletons : the skull, the backbone and ribs, fore and hind limbs were not merely present, they were built on the same plan. The similarity extended to the organs : the heart, the digestive system, the brain and nerves, all showed a resemblance too close to be merely accidental. Man and ape were even more alike ; man and fish less, though even here the resemblances were quite marked. There was yet, however, no obvious relation between the two great classes, plants and animals.

With a microscope even the gap between the two large groups was bridged. They both consisted of the small units we call cells. True, the plant cells were often rather different from animal cells, but they both contained the material, protoplasm. Moreover, the protoplasm of a plant cell showed many properties similar to that of an animal cell.

Even more resemblances have now been discovered. The chromosomes and the hereditary factors which they contain are common to plant cells and to animal cells. The resemblances of a boy to his parents have a similar cause to the resemblances of a dwarf pea to the stature of its parents.

Our study of heredity has shown us that changes are even now occurring in living organisms. It is believed that changes which have been occurring since life began on the earth have produced the living things which we now know. Long series of changes have occurred, in which the present population of plants and animals have developed from more simple types. This **evolution**, or development of existing types from earlier forms, helps to account for the resemblances and differences between the many forms of living organisms.

Evolution, the key to understanding life

Early motor cars were designed after the style of horse-drawn vehicles. They were slow, and a man with a red flag walked in front to warn road users of the new danger. From these beginnings have evolved the modern family car and the racing car, capable of speeds of 60 m.p.h. and 300 m.p.h. respectively. The evolution of the present cars from the early curiosities has taken only about 50 years. The evolution of present forms from the earliest forms of life is thought to have occupied 500 to 1,000 million years, while the earth in its present form has evolved from a mass of material torn away from the sun probably some 2,000 million years ago.

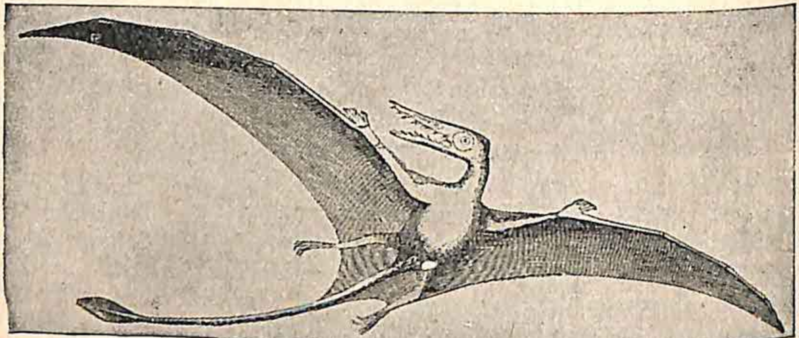
We know little of how life came into being, or of its earliest forms. As the earth gradually cooled down water collected on its surface, and, after a long time, minute living things, single masses of protoplasm, made their appearance. How they arose we do not know, but we believe that they arose in the seas, which are more suited to the life of simple organisms than land or even fresh water. The earliest forms were too soft to form fossils but from the simple living things which are now with us we can make guesses about their nature. When organisms were formed with harder parts, such as the cell walls of plants, or the hard case or bones of an animal, their remains were sometimes left to us in the forms we know as fossils. Fossils form one of the supports which strengthen our belief in the evolution of living things. We should examine their evidence more closely, and also the other facts which help our belief.

The evidence from fossils

When rocks are formed by the settling of sediment the oldest layers must be the deepest. The sedimentary rocks amount to layers over 40 miles in thickness, and the different layers contain the fossils of animals and plants, preserved in the layer which was being laid down at the time the organism died. We therefore know that the oldest fossils lie in the oldest (i.e. usually the deepest) rocks and we can make a picture for ourselves of the changes in the kinds of living things throughout the ages.

The oldest rocks contain fossils only of invertebrate animals. After them, in order, come the fishes, which are the simplest of the vertebrates, followed by amphibians and reptiles. The reptiles are followed by birds and mammals, at first of primitive types, later by more advanced types, and finally by man himself.

Each layer contains not only the new types but also such of the earlier types as have survived, altered in details by the passage of time. Thus, the fish layer contains not only fish, but invertebrates, the amphibian layer contains also fish and invertebrates, and so on through all the layers. Consequently the layers tell us, not only the order in which the types appeared, but also the changes which have occurred within each type. Everyone has seen pictures (e.g. Fig. 165) of prehistoric reptiles which once inhabited the earth. Reptiles were then the outstanding animals, but more intelligent kinds, the mammals, superseded them. Reptiles still exist, but in different forms, and they take a place inferior to mammals. Similarly the coming of man has resulted in the extinction of some mammals, and he occupies first place among those which survive.



[From Beadnell's " Picture Book of Evolution " (Watts).

FIG. 165.—A PREHISTORIC FLYING REPTILE.

Man's place in this succession is comparatively recent. Modern types of man occur only within the last 20,000 years. Earlier types, whose skulls have been found, made flint instruments, and must therefore be regarded as men. A modern game hunter would probably regard one of these as a new kind of beast and shoot it, if by chance he met one.

The horse has a long series of fossil ancestors forming a good record of progressive development. Early kinds lived in forests, but climatic changes formed grassy plains where concealment from enemies was impossible, and speed was necessary for escape. The fossil records show a steady increase in size, a change in teeth to grind the harder grasses of the plains, and above all a change from a five-toed, slow-moving animal to the horse, which runs on a single hoof on each foot, surpassing our own attempts at speed by running on tiptoe. Fig. 166 shows some of the stages of this transition.

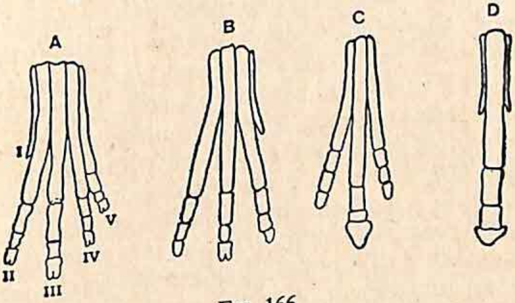


FIG. 166.

Evidence from geography

Geographers tell us that Australia was once joined to Asia by land, the join being by the route taken to-day by the flying services, that is, from the Malay States via the Dutch East Indies. The bridge was broken so long ago that many forms of present plants and animals had not originated. Australia therefore has a plant and animal life different from all other parts of the world. There are kangaroos, but, until introduced by man, no mammals of other continents. When these animals have been introduced, they have flourished (e.g. the sheep) and even become pests (e.g. the rabbit), so it was not unsuitability which prevented their development. They had spread over other parts, but could not cross the long stretch of sea to Australia.

Even the British Isles have minor examples of this sort. The wrens of St. Kilda, and the voles of the Orkneys are of types rather different from the corresponding mainland animals.

St. Helena is over 1,000 miles from the nearest land, and the effects of isolation here are very striking. There are no amphibians, reptiles, mammals or land birds native to the island, and over half the native plants and animals which can be seen by the unaided eye occur there, but nowhere else in the world.

Evidence from anatomy

The forelimbs of man and frog, the wings of birds and bats and the flipper of a whale are all built on the same general plan; a single bone in the upper limb, two in the lower limb, small bones at the wrist or its equivalent, and long bones in positions corresponding to the hand and fingers (Fig. 167). Other parts show similar resemblances. This utilisation of a common plan for so many types is in good agreement with the idea of evolution. Birds and mammals are evolved from a common type, reptiles, and the common plan, inherited from their reptilian ancestors, has remained the basis of all their general structures.

Man normally has no tail, but remnants of bones which formed a tail are present. On the nasal side of the eye man has a small, useless, triangular piece of flesh. In reptiles, and in many birds and mammals this is a transparent cover which can be flicked across to clean the surface of the eye.

Man's body is quite a museum of useless structures handed down from primitive ancestors. The passage from the ear to the back of the mouth is a relic of the gill clefts in our fish-like ancestors, but this has a new but definite use, to equalise pressures on the two sides of our eardrums.

How has evolution occurred?

The sum of the evidence in favour of evolution is overwhelming. We have seen but an infinitesimal fraction of the total evidence. Evolution, to a biologist, is a proved fact, but *how* exactly it has been brought about is a matter in which agreement is not yet quite general. There are two main theories as to how evolution, as a natural process, has been brought about. One of these was first put forward by Lamarck (a French biologist) and the other by Charles Darwin. Each theory has been modified in view of wider knowledge, but it is convenient to refer to the theories by the names of their originators.

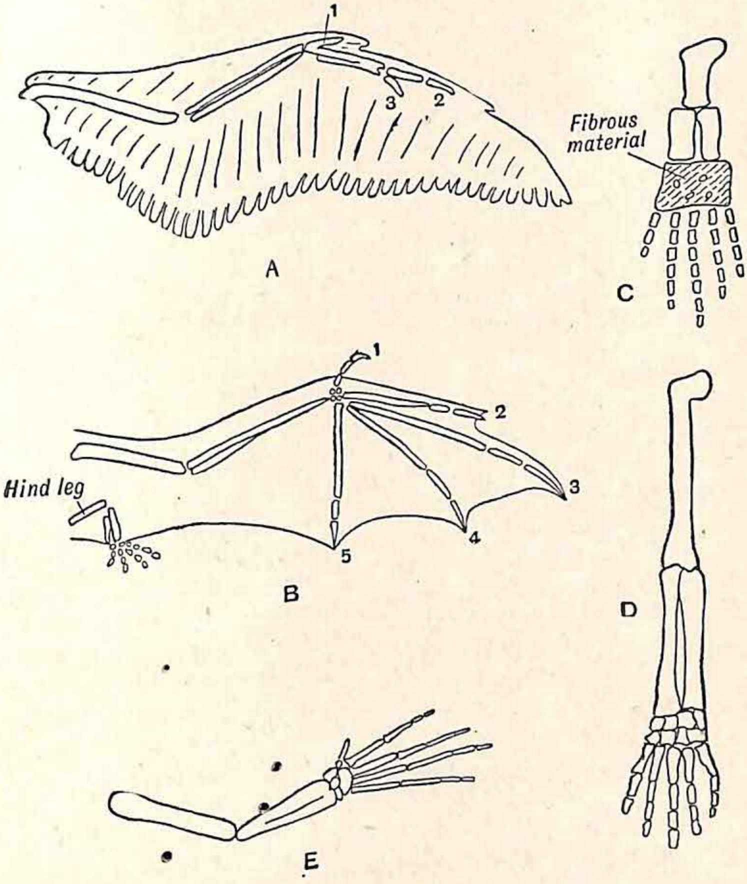


FIG. 167.

Forelimbs : A, bird ; B, bat ; C, whale ; D, man ; E, frog.

Lamarck : the inheritance of acquired characters

According to this theory an organism is affected by its surroundings, *and hands on some of the effect to its progeny.* The son of a good cricketer or pianist is often a very good performer himself. The followers of Lamarck would say that the son had benefited by the practice of the father.

The possibility of handing on an improvement to the next generation in this way is very attractive, but most biologists do not now accept this as a correct theory. They give two main reasons for their disbelief.

(1) Many of the examples quoted in its favour have been shown to be incorrect, or capable of another explanation. In the above example the son inherits his father's ability, but it is disputed that he benefits by his father's practice.

(2) Hereditary factors are carried in the chromosomes of the reproductive cells, but acquired characters, *as far as we can see*, only alter ordinary body cells, such as (in the example quoted), the muscle and nerve cells.

Darwinism

In 1859 Charles Darwin published a book "The Origin of Species," in which he gave his views on the ways in which evolution had occurred. The three main points of his theory are as follows.

(1) There is no *exact* resemblance between any two organisms. Accordingly there is **variation**, e.g. in intelligence, in strength, in ability to resist unfavourable conditions.

(2) All organisms produce more young than eventually survive and breed. There is consequently competition, perhaps for food, for shelter, for a place to breed. Darwin called this the **struggle for existence**. It does not imply that the competitors necessarily fight or even consciously compete. When food is scarce one may find food, eat and survive. The other may die.

(3) **Natural selection.**—In the case just discussed an animal with a superior sense of smell has a better chance of survival, and so of breeding. Consequently the next generation contains an increased proportion of animals with the better sense of smell while those with the inferior sense must be in gradually diminishing proportion.

The theory states that selection occurs and that variations of an advantageous nature are thereby favoured. For this to have an effect on evolution it is clearly necessary that the variations shall be inherited. It is at this point that we again tread on ground where agreement, even among biologists, is not quite unanimous. We have already seen that controversy still exists concerning the inheritance of variations produced by the environment. There is also some doubt as to the extent to which the variations caused by reshuffling of hereditary factors (Mendelism) is responsible for progress in evolution. On the other hand it is fairly generally agreed that mutations are responsible for definite evolutionary progress, though the extent to which the method is effective is still doubtful.

It is perhaps a fair summary of the views of the majority (but not all) of biologists to state the following :

(1) Natural selection is largely responsible for evolution.

(2) Variation due to environment is believed to be ineffective ; variation due to reshuffling of hereditary factors is probably effective to a limited extent, and mutation to a greater, but as yet unascertained extent.

We are clearly not in a position to be dogmatic as to *how* evolution has occurred, but the *fact* that it has occurred is undisputable. Future discoveries will probably throw more light on the methods by which evolution has taken place.

Adaptation

A noticeable feature of the frog is the admirable way in which the creature seems to be suited to the environment in which it lives. We may note the following points :

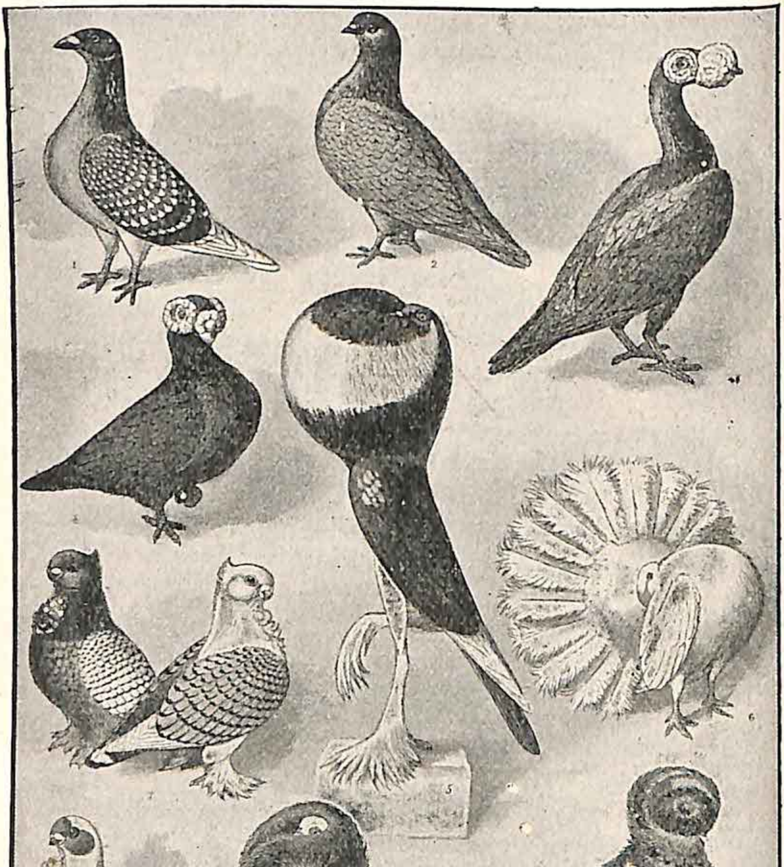
(1) It spends much time in water, and its hind feet are webbed, a definite help in swimming.

(2) It relies on a moist skin for a large proportion of its respiration, and it lives in damp places.

(3) It feeds on insects, and has a tongue, hinged at the front, which is very suitable for catching them.

(4) It is eaten by ducks, and has a dark blotched coloration in its upper parts which helps to conceal it.

Consideration of these points enables us to say that a frog is very well **adapted** to its mode of life. This adaptation of organisms to their surroundings is very common. White animals and birds are in a higher proportion in the polar regions than elsewhere. Their colour diminishes loss of body heat and helps to conceal them from their enemies or their prey. The dark skin of the negro prevents penetration and damage by the sun's


1
2
4
3
5
6
7
8
9
10

[*From Beadnell's " Picture Book of Evolution" (Watts).*

FIG. 168.—VARIETIES OF PIGEONS.

rays. Deserts contain a high proportion of succulents, plants such as the cacti, whose nature enables them to store large quantities of water against periods of drought.

Natural selection of advantageous variations may account for many of these adaptations. The white-coated animal would lose less heat, need less food, and therefore be more likely to survive the arctic winter than an animal exactly similar except for the colour of his coat. We should, however, be cautious and not dogmatic in the matter. Most desert animals are sandy coloured, even the nocturnal ones, where colour does not seem very helpful. On the other hand, a number of black desert animals seem to hold their own successfully, so that processes other than natural selection may be at work.

Artificial selection

Man has played a direct part in evolution by selecting and breeding animals and plants to suit his own purposes. His part can be regarded as **artificial selection** as opposed to the slower process of natural selection. We have already seen how it has been applied in conjunction with a knowledge of heredity, to produce improved kinds of sugar cane and wheat.

The snapdragon can be quoted to illustrate how quickly new varieties may be obtained. There are two wild flowers, one red, one yellow, closely related to our garden snapdragons. When crossed they give a red hybrid. On crossing these red hybrids within themselves, twenty-four separate varieties are obtained owing to reshuffling of the factors of heredity.

The enormous variety of tame pigeons (Fig. 168) has been produced by artificial selection from a single type of wild bird, the rock dove. The variety of dogs has also been produced by artificial selection, but in this case several different kinds of wild dogs have contributed to the variety.

APPENDIX

SPECIFIC HEATS OF COMMON SUBSTANCES

Substance	Specific heat	Substance	Specific heat
Aluminium	0·21	Mercury	0·033
Brass	0·088–0·093	Tin	0·054
Copper	0·093	Alcohol	0·55–0·65
Iron	0·113	Paraffin	0·52–0·54
Lead	0·032	Turpentine	0·42–0·46
Marble	0·21	Water	1

QUESTIONS

CHAPTER 1

(1) Name two compound gases which will burn. Briefly describe how you would prepare one of them. Of what importance in ordinary life is the gas you select?

(2) What is a hydrocarbon? Give examples. What substances are formed when a hydrocarbon is burnt completely? How do you account for the presence of carbon monoxide in the exhaust gases from the engine of a car?

(3) Why is it incorrect to say that coal is burnt in the retorts at the gas works?

(4) What is the function of (*a*) condensers, (*b*) scrubbers, and (*c*) purifiers in the manufacture of coal-gas? What by-products are obtained from (*a*) and (*c*)?

(5) Name four substances which are obtained from coal-tar, and give an account of their everyday uses.

(6) When a kettle is heated on a gas-ring, it often becomes covered with a liquid. What is the liquid, and how do you account for its formation?

(7) Trace the possible connection between coal and a dark blue coat.

(8) Explain how petroleum occurs in the earth's crust. Name four substances which are obtained from petroleum and give an account of their everyday uses.

CHAPTER 3

(1) Explain the advantages of the body form of ivy over that of a small bush, when the two are living in a dense wood.

(2) State briefly the conditions under which plants can build carbohydrates from simple chemical compounds.

(3) What is meant by a control experiment? Why are control experiments particularly necessary in biological work?

(4) Describe experiments which illustrate the following aspects of photosynthesis: (*a*) the necessity of light; (*b*) the necessity of chlorophyll.

(5) How can the fact that chlorophyll disappears from parts of plants which are kept in complete darkness be usefully applied?

(6) Explain, from a scientific standpoint, the statement that every human action is a transformed sunbeam.

(7) The stomata of plants usually open in bright light, but remain closed during the hours of darkness. Explain any advantages this has for the process of photosynthesis.

CHAPTER 4

For values of specific heats see p. 236.

(1) How much water at 200° F. must be added to 10 lb. of water at 60° F. so that the temperature of the mixture is 120° F. ?

(2) Find the resulting temperature when the following quantities of water are mixed :

(*a*) 200 grm. at 15° C. with 140 grm. at 100° C.
(*b*) 90 grm. at 17° C. with 40 grm. at 82° C.

(3) Explain what is meant by (*a*) thermal capacity, (*b*) specific heat. What is the thermal capacity of an aluminium saucepan weighing 300 grm.?

(4) Describe how you would attempt to find out how much heat is given out per minute by an electric light bulb.

(5) When 100 grm. of copper at 100° C. are put into 155 grm. of petroleum at 13° C., the resulting temperature is 22° C. What is the specific heat of petroleum?

(6) If 200 grm. of water at 10° C. are heated electrically to 28° C. in 10 mins., how many calories per minute pass into the water?

When the water is replaced by an equal volume of glycerine of density 1·2 grm. per c.c. the temperature rises from 10° C. to 30° C. in 8 mins. Calculate the specific heat of glycerine.

(7) 25 gallons of water, for a bath, are heated from 50° F. to 100° F. by means of a gas heater. Assuming that half the heat of combustion of the gas goes into the water, find the cost if the gas is charged at 9*d*. per therm. (1 gallon of water weighs 10 lb.)

(8) The melting-point of bismuth is 270° C., its specific heat 0·30, and its latent heat 13 cals. per grm. Explain what is meant by these statements. How many calories are required to raise 5 grm. of bismuth from 20° C. to its melting-point and to melt it?

(9) How many calories are required to change 50 grm. of ice at 0° C. into steam at 100° C.?

(10) An iron ball at 100° C. is placed in the cavity of a Black's ice calorimeter and 16 grm. of water are formed in the cavity. What is the thermal capacity of the ball?

CHAPTER 5

(1) State the kinds of food which would be specially needed in the case of (*a*) a rapidly growing boy ; (*b*) an adult who is doing hard physical work. Give your reasons.

(2) Why is a diet containing only water and carefully purified carbohydrates, fats and proteins unsuitable for human beings?

(3) What do you understand by the term enzyme? What advantages does the body obtain by the use of enzymes?

(4) Why should we chew starchy food? Suggest reasons why non-starchy food should also be chewed.

(5) An egg contains valuable amounts of fats and proteins. Give an outline of the changes which occur in the digestion of a boiled egg.

(6) Outline briefly the part played by glands in the process of digestion.

(7) Assume that the whole of a man's stomach had to be removed on account of some defect. Give any reasons you can why the patient might survive. From what inconveniences do you consider he would suffer in later life?

(8) What advantages have fresh fruits over cooked fruits, and steamed vegetables over boiled ones? Give reasons for preferring wholemeal bread to white bread.

(9) Outline the functions of the large intestine. Why is it important that we should get rid of its contents without undue delay, and at regular intervals?

CHAPTER 6

(1) Give an account of the manufacture of nitric acid from nitrogen, hydrogen, air and water.

(2) Name two nitrates and describe how you would prepare samples of them in the laboratory.

(3) What do you know of the use of nitric acid in making (*a*) an explosive, (*b*) a dye?

(4) What are the following: (*a*) cellulose, (*b*) celluloid, (*c*) gun-cotton, (*d*) cordite?

CHAPTER 7

(1) Why should we not scratch the skin when it itches? Why should increased cleanliness of clothes and body be accompanied by a decrease in disease?

(2) Explain how life may be said to depend on the destruction of living things.

(3) How do toadstools get their food? In view of their method of feeding, why do we regard them as plants rather than animals?

(4) In what different ways can parasites be injurious to their hosts?

(5) Patients suffering from certain diseases are told to avoid crowded places, or are even sent to an isolation hospital. Why?

(6) Give an account of the methods which can be used to free a solid object from germs.

(7) What are the advantages of a town large-scale water supply over the use of a number of small private wells?

(8) Explain the processes which can be used to destroy germs in materials which are to be used as food.

(9) Describe two useful processes which are carried out by bacteria.

CHAPTER 8

(1) Describe how you would use (*a*) disc weights, (*b*) a spring balance to find the force required just to pull a wooden block along the bench.

(2) Why is it easier to balance a wheelbarrow with two wheels than one, and to manœuvre more easily under the reverse conditions?

(3) The centre of gravity of a cardboard triangle is $\frac{1}{3}$ of the way up the line joining the mid-point of the base to the opposite corner. Describe in detail how you would verify this experimentally.

(4) Explain why it is almost impossible to balance a pencil on its point.

(5) Indicate and describe the action of the simple machines used in a "Geryk" pump (Book I, p. 138).

(6) Classify, with reasons, the following types of levers: (*a*) tyre-lever in use, (*b*) oar of a rowing boat, (*c*) tumbler switch for electric light, (*d*) spade used in digging.

(7) A ladder lies on the ground perpendicular to a wall. A man raises the ladder to a vertical position by lifting the end further from the wall and walking towards the wall. Explain, with diagrams, how the ladder behaves like different orders of levers.

(8) A metre scale, pivoted at its mid-point, has 100 grm. suspended from the 10 cm. mark and 300 grm. from the 90 cm. mark. From what point must a 400-grm. weight be suspended for the scale to balance?

(9) Is the mechanical advantage of a pair of scissors constant? Explain.

(10) Explain the terms mechanical advantage, velocity ratio, efficiency. What is the efficiency of a machine whose mechanical advantage is 15 and velocity ratio 20?

(11) (*a*) How would you select and arrange two cog-wheels to give a velocity ratio of 5? (*b*) Do the cog-wheels of a clock increase or decrease the mechanical advantage?

(12) Sketch a block and tackle having three pulleys in each block and deduce its velocity ratio. If an effort of 20 lb. raises a load of 90 lb., calculate (*a*) the mechanical advantage, (*b*) the efficiency.

(13) A man weighing 10 stone carries a load of 36 lb. up a flight of stairs of vertical height 30 ft. in 8 secs. At what power does he work? What percentage of the work done is useful?

CHAPTER 9

(1) Describe four examples which prove that a moving object possesses energy.

(2) Describe the energy changes which occur when a ball bounces. Why are successive rebounds less high?

(3) Summarise the evidence that heat is a form of energy.

(4) Show that the heat given off by an electric radiator is derived from the sun.

(5) A rock weighing 80 lb. falls through a vertical height of 389 ft. If all its energy is converted into heat on impact with the ground, how much heat will be produced? [778 ft.-lb. = 1 B.Th.U.]

(6) An electric lamp is marked 210 volts, 100 watts. What do these figures mean? What current does it take? What is its resistance? For how long can the lamp be used for the consumption of 1 " unit "?

(7) An electric motor, run from 200 volts supply, takes 15 amps. of current. At what rate is energy supplied? If it delivers 3 H.P., what is its efficiency? [746 watts = 1 H.P.]

(8) A heating coil, immersed in 200 grm. of water, causes the temperature to rise at the rate of 1° C. per minute. The current in the coil is 1 amp. and the pressure difference across it 14 volts. How many joules are equivalent to 1 calorie?

(9) Explain why the terrestrial supply of energy gradually becomes unavailable. Describe *one* way in which a new supply is obtained.

(10) Explain why green plants are essential to animal life.

CHAPTER 10

(1) A model yacht was becalmed near the middle of a large pond. To recover it, the owner threw stones into the water near the yacht. Criticise this action.

(2) Which particles in a wave-form are travelling (*a*) fastest, (*b*) slowest? What is the distance between two consecutive particles in (*a*)?

(3) If you watch the waves near the sea-shore you will notice that they bunch together as they approach the shore. Can you account for this?

(4) Calculate the frequency of a wireless transmitter broadcasting on wave-lengths of (*a*) 30 metres, (*b*) 480 metres.

(5) State *two* reasons why it is difficult to produce absolute silence of the electric bell operating in the "evacuated" bell-jar (Fig. 72).

(6) When sound waves pass through air, which are the regions of (*a*) greatest density, (*b*) normal density, (*c*) least density of the air? Trace the sequence of density values in any particular region.

(7) When sound waves pass through air, what is the distance between the centres of (*a*) consecutive regions of greatest density, (*b*) consecutive regions of greatest and least density? Give reasons for your answers.

(8) If a note sounding with a frequency of 256 per sec. be regarded as doh, calculate the frequencies of me, soh and doh$^{\mathrm{I}}$ based on this original frequency. Calculate also the frequencies of me$^{\mathrm{I}}$, soh$^{\mathrm{I}}$ and doh$^{\mathrm{II}}$ in the scale of the next higher octave.

(9) A horn is blown at a distance of 405 ft. from a high cliff. If there is to be a silent interval of 0·5 sec. between the true sound and the echo, for what time may the horn be sounded? If the frequency is 384 per sec., how many waves will be propagated from the source?

Velocity of sound in air $=1{,}080$ ft. per sec.

(10) Explain the rise in pitch of the sound produced as water trickles noisily from an open tap into a tall cylinder standing below it.

(11) When a concert is broadcast from a public hall in London, listeners at home in any part of the British Isles hear the reproduced sounds before the audience at the back of the hall hears the actual sounds. How is this explained?

CHAPTER 11

(1) If it is not possible to enter a wire cage containing a pet animal, how may a clear photograph of the animal be obtained without photographing also the wires between the animal and the camera?

(2) Explain why photographs obtained with an ordinary camera are *very* much smaller than the objects which they represent.

(3) A boy stepping from a bright sunlit street into a house complained that he could hardly see. How do you explain his disadvantage and why is it quickly removed?

(4) If the driving mirror of a car is inside the vehicle, it is a plane mirror. Why is a convex mirror not suitable for use inside the car?

(5) A small object is to be examined by means of a convex lens of focal length, 5 cm. If the image is to be viewed at a distance of 25 cm. from the lens, where must the object be placed, and what is the magnification produced? Explain the construction of your diagram.

(6) A person wears spectacles constructed with a concave lens for the right eye and a piece of plane glass for the left eye. Comment on his eyesight.

(7) Explain fully why the objective of a compound microscope should have a very short focal length.

(8) Some people use spectacles with concave lenses out of doors and yet do not need to wear them indoors, especially for reading. Explain why they can discard them indoors.

(9) If a person can read a newspaper which is held about 36 in. from his eyes, does it follow that he has good eyesight? Explain carefully.

CHAPTER 12

(1) Explain why (*a*) the blade of a skate should be narrow, and (*b*) the runners of a sleigh fairly broad.

(2) If the weight of a cubic foot of water is 62·5 lb., calculate the pressure on the base of a reservoir in which the water is 50 ft. deep. State the value in (*a*) tons per sq. ft., (*b*) lb. per sq. in.

(3) What conclusion may be drawn about the value of pressure at different levels in a liquid, by observing the curvatures of the streams issuing from the reservoir in Expt. B, p. 152?

(4) If the density of mercury is 13·6 grm. per c.c., calculate the atmospheric pressure when the height of the barometer is 75 cm. From your result, deduce the height of a water column exerting the same pressure, and point out why mercury is the only liquid really convenient for use in barometers.

(5) In repeating the process of finding the density of oil by means of a U-tube, a boy added more oil to the wrong limb. Is it possible still to proceed with the experiment or must a fresh start be made? Explain fully.

(6) Is it possible in Hare's apparatus for the surfaces of the columns of liquids of different density to be on the same level? Explain clearly.

(7) Can satisfactory values for a density be obtained either by means of a U-tube or Hare's apparatus if the tubes are tilted?

(8) Some mercury is poured into a U-tube, and a column of water 45 cm. high on the mercury in one limb causes the surface in the other limb to rise 1·65 cm. Calculate the density of mercury. Do you consider the U-tube method a good one for finding the density of mercury?

(9) A barometer contains a little air above the mercury column. When the true reading should be 74 cm., the observed height is only 73·6 cm. Will the error still be 0·4 cm. on a day when the true reading is 77 cm.?

(10) The capacity of a bicycle tyre is 120 cu. in. If 5 cu. in. of air are transferred into the tyre by each stroke of the inflator, calculate the number of strokes required to produce a pressure of 2·5 atmospheres in the tyre, which originally contained air at atmospheric pressure.

(11) Trace and explain the *air* movements during the first few strokes of (*a*) a lift pump, (*b*) a force pump.

(12) If a lift pump has been idle for some time it is usually necessary to pour water into the top of the cylinder before the pump will work satisfactorily. What explanation do you offer for this procedure?

(13) Explain why a siphon could not empty a tank containing water to a depth of 40 ft.

(14) A sealed celluloid "diver" is constructed so that it rests vertically immersed with the tip of its head just at the surface of some water which nearly fills a gas jar. A thin sheet of rubber is stretched and securely bound over the top of the jar to make it airtight. Why does the diver sink when this rubber sheet is pressed inwards?

(15) On a bench, two similar blocks of wood, 6 in. × 4 in. × 3 in. and weighing 30 oz., are placed about $\frac{1}{2}$ in. apart with their largest surfaces (24 sq. in.) vertical and parallel. A paper bag is inserted between the blocks and inflated from a boy's lungs. Explain why the blocks topple over.

CHAPTER 13

(1) Give an account of the American process for extracting sulphur.

(2) If you hold a lump of roll sulphur in your warm hand, the sulphur cracks. Explain why this happens.

(3) How do you account for the tarnishing of silver objects? State whether you would expect tarnishing to be more marked in the country or in a town; give reasons.

(4) Why does a silver coin which is kept in contact with an india-rubber become black?

(5) In what way is sulphur connected with (*a*) plants, (*b*) matches, (*c*) bicycle tyres?

(6) Sulphur dioxide is a bleaching agent. What does this mean? Explain the bleaching action. Why do straw hats become yellow with age?

(7) What is chemical wood-pulp? How does it differ from the wood-pulp used for newspapers?

(8) Starting with sulphur, describe how you would obtain a specimen of concentrated sulphuric acid. Quote one test you could apply to your product to prove that it is concentrated sulphuric acid.

(9) Describe how you would prepare some copper sulphate crystals, starting with copper and concentrated sulphuric acid. [Black cuprous sulphide does not dissolve in water.]

(10) What do you know of the use of sulphuric acid in making (*a*) an artificial manure, (*b*) lubricating oil, and (*c*) sweets?

CHAPTER 14

(1) Starting with rock salt, describe how you would prepare concentrated hydrochloric acid.

(2) Name any four salts (excluding common salt) which are used in everyday life, and give an account of the uses of each salt you select.

(3) Explain, so far as you can, what happens in (*a*) exposing, (*b*) developing, and (*c*) fixing, a photographic print.

(4) Describe how you could obtain some chlorine from common salt.

(5) How would you attempt to make a specimen of bleaching powder? How would you use it to bleach a piece of cloth?

(6) What is the connection between chlorine and (*a*) a car fire-extinguisher, (*b*) the prevention of disease?

CHAPTER 16

(1) What advantages are there in knowing the life-history of an insect pest? Explain your answer by reference to a particular insect.

(2) In what ways can insects cause disease? What methods can be employed to reduce the danger?

(3) Make a list of insects which cause harm to man by damaging his property, domestic animals or crops. State briefly how the damage is caused in each case.

(4) How can flies be reduced in number effectively? Which are the best methods to use, and why? If "swatting" is used to kill house-flies, what time of the year is it most usefully carried out? Give your reasons.

CHAPTER 18

(1) Lack of pigment (albinism) is recessive both to brown and to blue eye colour, while blue is recessive to brown. What different kinds of animals would you expect, and in what proportion, when crossing brown-

eyed and blue-eyed individuals each of which carries a recessive albino factor ?

(2) What advantages has a breeder of plants (e.g. potatoes) over an animal breeder ?

(3) Explain separately the parts played by (*a*) heredity, and (*b*) environment (e.g. education, upbringing, feeding), in determining the mental and physical development of a boy or girl.

(4) State briefly any reasons you have for believing that gradual changes in the nature of living things on the earth have taken place during a long period of time.

(5) If you wish to breed hens for egg production, why is it desirable to start with pedigree birds rather than with a miscellaneous collection of prolific egg layers ?

(6) Suggest ways in which scientific knowledge can enable a given part of the earth to feed a larger population than hitherto.

(7) To what extent do you consider that the struggle for existence in man resembles that among other animals ? What differences are there in the two cases ?

(8) Suggest methods by which the truth or otherwise of Lamarck's theory of inheritance might be investigated experimentally.

(9) A few very successful plant and animal breeders have had no knowledge of Mendelism. Suggest reasons why Mendel's discoveries are nevertheless of importance to the breeding industries.

(10) What differences from its actual population of native animals would you expect to find if Australia were joined to Asia by land ?

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